AEROBIC FITNESS AND THE ATTENTIONAL BLINK IN PREADOLESCENT CHILDREN

BY

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DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Kinesiology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2012

Urbana, Illinois

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Abstract

Given the growing concern that children in today's industrialized and technologically advanced society are becoming more sedentary and less fit, a greater understanding of the extent to which aerobic fitness relates to brain health and cognition during development is of increasing importance. Given that temporal dynamics has not been examined to link the relation of aerobic fitness with cognition in preadolescent children, this study sought to employ neuroelectric and behavioral measures under the attentional blink task to examine this relationship. Using a cross-sectional design, response accuracy and event-related brain potentials were assessed for preadolescent children with different levels of aerobic fitness. Results indicated that higher-fit children exhibited greater response accuracy and enhanced attentional resources distribution compared to lower-fit children. These findings indicate that aerobic fitness may benefit cognitive health in particular with temporal dynamics during preadolescent maturation.

To My Mom and My Dad

Acknowledgements

The completion of my doctoral dissertation would not have been possible without the help of several individuals who in one way or another contributed their valuable assistance in preparation and completion of this study. First and foremost, I would like to express my upmost gratitude to my advisor Dr. Charles H. Hillman for all of the guidance and support he has given me throughout my doctorate career. He was always supportive throughout the progression. Most importantly, Chuck has guided me not only through the research process, but through the tumult a graduate student may have to go through. I would also like to thank my committee members Dr. Neal Cohen, Dr. Edward McAuley, and Dr. Steven Petruzzello. I have been fortunate enough to have worked with such great scholars, whose valuable suggestions have been amazingly helpful throughout my dissertation processes.

Special thanks are also necessary to my colleagues (graduate and undergraduate) who helped me through the data collection process and participant scheduling. Lauren Raine was vital in this process and helped to make my life easier.

Finally, I would like to thank my girlfriend for her patience and understanding of my priorities in my research. She was always there cheering me up and stood by me through the good times and bad.

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CHAPTER 1

INTRODUCTION

Recent studies have indicated a positive effect of physical activity on weight control, bone mass, muscle strength, and the reduced risk of heart disease and certain cancers (USDHHS, 2008). In children, physical activity has many benefits, such as improved physical fitness and reduced risk of disease (Strong et al., 2005). Unfortunately, children in today's industrialized and technologically advanced society have become increasingly sedentary and unfit, exacerbating the prevalence of certain physical diseases including cardiovascular disease, colon cancer, and type-2 diabetes (DHHS & DOE, 2000). Further, recent trends in school policy are reducing opportunities for physical activity (e.g., physical education, recess) from the school day to create additional instruction on formal academic subjects (Thomas, 2004). As such, childhood physical inactivity and a sedentary lifestyle often persist across the lifespan (Janz, Dawson, & Mahoney, 2000), potentially resulting in ill health in later life (Anderson, Crespo, Barlett, Cheskin, & Pratt, 1998; Freedman, Khan, Dietz, Srinivasan, & Berenson, 2001; Sisson et al., 2009). Accordingly, overwhelming evidence has suggested that physical inactivity during childhood is associated with decreased health and function across the lifespan.

In addition to decreases in physical health, a growing body of research has emerged indicating a positive relationship between physical activity, cognition, and brain health across the lifespan (see Hillman, Erickson, & Kramer, 2008 for review). In older adults, it has been well-established that aerobic fitness relates to improvements in cognitive functions (Colcombe & Kramer, 2003). Relative to children, a limited meta-analytical review initially indicated that physical activity has a small, but positive effect on cognition (Sibley & Etnier, 2003). A more recent review of the longitudinal studies with children indicated improved cognitive performance following participation in physical activity training (Tomporowski et al., 2008). As such, several aspects of cognition, including cognitive control, attention, perceptual motor skills, visual-motor coordination, and academic performance, have been investigated to elucidate its relation with aerobic fitness in children (Sibley & Etnier, 2003; Tomporowski et al., 2008). However, given that the study of physical activity to brain health and cognition is in its infancy, our knowledgebase regarding several areas of study remains limited.

Specifically, the temporal dynamics of visual attention in children has not been examined as a function of fitness, and thus our knowledge of fitness effects on attention remains incomplete. The temporal dynamics of visual attention describes how attention recovers over time once it has been allocated to a stimulus or event (Raymond, Shapiro, & Arnell, 1992). In the last two decades, researchers have been intensely interested in the mechanisms and processes of deploying attention across time (see Dux & Marois, 2009; Martens & Wyble, 2010; Shapiro, Arnell, & Raymond, 1997 for review) through the repaid serial visual presentation (RSVP) paradigm (Raymond et al., 1992). A RSVP stream presents sequential stimuli such as numbers or symbols in the same location and in rapid succession, at rates of approximately 10 items per second. This paradigm requires participants to identify two unspecified letters (the targets, referred to as T1 and T2, respectively) embedded within a stream of distractors. The temporal interval or lag between T1 and T2 is varied systematically. Of interest, is the performance of participants on T2 detection, given that they have correctly identified T1 (the response accuracy for T2 on those trials for which T1 was accurately identified, denoted as T2|T1). As such, the attentional blink (AB) refers to the reduced accuracy of reporting either the presence or identity of T2 when it occurs 200 − 500 ms after T1 (the AB time window; Broadbent & Broadbent, 1987; Raymond et al., 1992; Shapiro, Raymond, & Arnell, 1994; Vogel, Luck, Shapiro, 1998), whereas T2|T1 gradually recovers when the lag increases. Generally, the AB is thought to occur due to competition between the two targets for limited attentional resources (Shapiro et al., 1997) and particular difficulty in consolidating T2 into a reportable working-memory representation (Martens, Wolters, & Van Raamsdonk, 2002; Rolke, Heil, Streb, & Henninghausen, 2001; Vogel et al., 1998; Luck, Vogel, & Shapiro, 1996). However, the precise adaptive significance behind the AB remains unclear.

Irrespective of which model best fits the mechanisms underlying the AB, a multifactorial origin of AB has been concluded. Specifically, the AB reflects the competition between targets for attentional resources, not only for working memory encoding, episodic registration, and response selection (and perhaps additional processes that have yet to be identified), but also for the enhancement of target representations and the inhibition of distractors (see Dux & Marois, 2009 for review). Accordingly, a promising approach that has been widely used is to compare specific groups of participants that demonstrate varying degrees of AB magnitude (see Martens and Wyble, 2010 for review). For instance, the AB magnitude has relevance to clinical settings, given that it helps elucidate cognitive limitations in patients (Husain and Rorden, 2003; Husain, Shapiro, Martin, & Kennard, 1997), elderly (Geirgiou-Karistianis et al., 2007; Lahar et al., 2001; Maciokas & Crognale, 2003), and children with attention deficit hyperactivity disorder (ADHD; Hollingsworth, McAuliffe, & Knowlton, 2001; Li, Lin, Chang, & Hung, 2004), who show a deeper or wider AB than their healthy (or younger) counterparts. That is, the AB is greater in magnitude or temporally more extended. Regarding normal populations, an attenuated AB magnitude has been shown after three months of intensive mental training (Slagter et al., 2007) and in people who often play or have been under training of the action video games (Green & Bavelier, 2003), suggesting that temporal dynamics is allocated differently as a function of lifestyle or health factors. With respect to children, previous studies have found that AB duration is progressively longer across adolescence through the study of 7-, 12-, and 15-year-old children (Garrad-Cole et al., 2011). Such findings are consonant with the work of Dye and Bavelier (2010), who observed 7-13 year olds needed more time to recover attentional resources than 14-22 year olds. Taken together, the data suggests that AB magnitude might be a useful index of the temporal resolution of visual attention to examine group differences as a function of development or aging.

With respect to the brain network involved in the AB, neuroimaging studies have evidenced an interactive network consisting of lateral-frontal (for the processing and maintenance of goals and target specifications), infero-temporal (for target identification), posterior-parietal (for target selection), and occipital (for extraction of stimulus characteristics) brain regions, suggested to be associated with the dynamics of attentional selection and processing that result in the AB (see Hommel et al., 2006; Martens & Wyble, 2010 for review). Regarding the role of the frontal cortex in the AB, it may be conceived of as the maintenance of task goals requiring the provision of functional top-down support (see Hommel et al., 2006 for review), given that the activation of the lateral-frontal cortex has been associated with selection problems induced by temporally close distractors (Marois, Chun, & Gore, 2000) or competing targets (Feinstein, Stein, Gastillo, & Paulus, 2004; Marcantoni, Lepage, Beaudoin, Bourgouin, Richer, 2003; Moris, Yi, Chun, 2004). For instance, increased activation of the anterior cingulate in the AB task was associated with success in detecting a temporally close T2 (Gross et al., 2004; Marois et al., 2000; 2004). Taken together, some specific brain region (i.e., the frontal lobe) may play an important role in AB performance based on previous neuroimaging studies.

However, with its excellent temporal resolution, event-related brain potentials (ERPs) may alternatively provide distinct cognitive processes of stimuli (i.e., T1, T2, and distractors) presented in the AB paradigm. In general, beyond the assessment of overt task performance (i.e., response accuracy and reaction time [RT]), ERPs represent an additional means of gaining insight into the underlying mechanisms involved with cognitive function. That is, ERPs provide information regarding a subset of processes that occur between stimulus engagement and response execution. For instance, the P3 (known as P300 or P3b) represents neuronal activity associated with revision of the mental representation of the previous event within the stimulus environment (Donchin, 1981). The amplitude of P3 is thought to reflect the allocation of attentional resources when working memory is updated (Donchin & Coles, 1988), such that the P3 is sensitive to the allocation of attentional resources during stimulus engagement (Polich, 2007). P3 timing, marked by its peak latency, is considered to represent stimulus classification and evaluation speed independent of response selection and action (Verleger, 1997; Duncan-Johnson, 1981). Accordingly, the assessment of ERPs may allow us to better understand the neural correlates of AB. Based on several leading models/theories (i.e., Chun & Potter, 1995; Shapiro et al., 1994), cognitive accounts of AB have commonly held that there is a capacity-limited stage in stimulus processing and that competition between different stimuli for limited processing resources underlies the AB effect. Consonant with this idea, the distribution of limited brain resources has been linked with the T1-elicited P3 component. Previous ERP studies found that the ability to accurately identify T2 is related to the latency and/or amplitude of the T1-elicited P3 (Martens, Munneke, Smid, & Johnson, 2006; Sergent, Baillet, & Dehaene, 2005; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006; Slagter et al., 2007; Martens, Elmallah, London, & Johnson, 2006). Specifically, smaller T1-elicited P3 amplitude has been observed in trials in which T2 was confirmed versus missed (Sergent et al., 2005). In addition, a T1-elicited P3 with smaller amplitude (Shapiro et al., 2006) or shorter latency (Martens et al., 2006b) has been observed in people who exhibited a relatively smaller AB magnitude, suggesting a greater ability to allocate limited resource or to identify targets more rapidly, which may lead to an earlier consolidation of relevant information. Taken together, these finding indicated that T1-elicited P3 may reflect the level of competition between T1 and T2.

Thus far, with two exceptions (Martens et al., 2006b; Slagter et al., 2007), there are only a few studies using ERP methods to compare specific groups of participants. Specifically, Slagter and colleagues (2007) conducted a longitudinal study investigating the effects of three months of intensive mental training on the distribution of limited attentional resources through the AB paradigm. Results revealed that participants with three months of mental training exhibited an attenuated AB and reduced brain-resource allocation to T1, as reflected by decreased T1-elicited P3 amplitude (Slagter et al., 2007). Slagter and colleagues (2007) suggested that the ability to accurately identify T2 might depend upon the efficient deployment of resources to T1 and further concluded that mental training may facilitate increased control over the distribution of limited brain resources.

Interestingly, similar to the benefit of mental training on neural resources allocation, recent neuroelectric studies using ERPs have supported the positive relation of aerobic fitness with neurocognitive function across the lifespan (see Hillman et al., 2008; Kramer & Hillman, 2006; Hillman, Kamijo, & Pontifex, 2011, for review). This relation has been extended into children populations (Hillman, Buck, Themanson, Potifex, & Castelli, 2009; Hillman, Castelli, & Buck, 2005; Potifex et al., 2011). Specifically, the P3 component has been compared in preadolescent children with different levels of fitness during cognitive tasks, with larger P3 amplitude (Hillman et al., 2005; 2009) and shorter P3 latency (Hillman et al., 2005) observed in higher-fit children compared to their lower-fit counterparts. These findings were replicated in Pontifex et al. (2011), as they observed overall larger P3 amplitude in higher-fit children through a manipulation of stimulus-response compatibility (i.e., cognitive flexibility) during a flanker task. Collectively, these ERP studies using a variety of cognitive tasks suggested that aerobic fitness may promote better cognitive and brain health through improvements in the allocation of attentional resources, reflecting by increased P3 amplitude and/or shorter P3 latency.

Despite these seemingly disparate bodies of literature, there are some striking similarities between the aspects of cognition that are related to aerobic fitness and those which exhibit AB-related deficits. However, to date, no prior research has investigated the relationship between aerobic fitness and AB in children or adults. Accordingly, the main purpose of present study was to examine whether the T1-elicited P3 component, T2-elicited P3 component, and AB magnitude reflect the positive relation of aerobic fitness with cognitive processes during a temporal dynamics task. Given that previous studies showed that aerobic fitness may promote cognitive function through effective attentional resources distribution, (Hillman et al., 2005; 2009; Pontifex et al., 2011), it is possible that aerobic fitness may benefit temporal dynamics through an overall reduction in attentional resources distribution to both targets within a limited brain resources. That is, the temporal nature of the task warrants efficiency or economy of resources for successful task performance, and it is posited that fitness may benefit such attentional resource distribution. Accordingly, it was hypothesized that 1) higher-fit children would exhibit a smaller AB magnitude compared to lower-fit children, indicating that aerobic exercise has a positive association with behavioral indices of temporal dynamics; 2) higher-fit children would exhibit a decreased T1-elicited P3 amplitude and a shorter T1-elicited P3 latency compared to lower-fit children, indicating that aerobic fitness has a positive association with neuroelectric indices of temporal dynamics; and 3) higher-fit children would exhibit a decreased T2-elicited P3 amplitude and a shorter T2-elicited P3 latency compared to lower-fit children, indicating that aerobic fitness has a positive association with neuroelectric indices of temporal dynamics. Thus, the study proposed herein may provide additional insight into the relation of aerobic fitness to temporal dynamics and indicate that physical activity may benefit the increased cognitive health and effective functioning during preadolescent maturation.

CHAPTER 2

REVIEW OF LITERATURE

To better understand why aerobic fitness may modulate neurocognitive functions related to temporal dynamics in preadolescent children, it is necessary to review the existing literature on aerobic fitness, attentional blink, and neuroelectric indices of cognition. First, a literature review of the study of aerobic fitness with cognition in children will be discussed. Second, a theoretical overview of AB, its proposed neural correlates, and its application to clinical settings and healthy populations will be discussed to provide a framework for understanding the AB. Finally, the existing literature on neuroelectric indices of cognitive processes related to both AB and aerobic fitness will be examined to provide justifications for the present investigation.

Aerobic Fitness, Cognition, and Children

There is a growing concern that children in today's industrialized and technologically advanced society are becoming more sedentary and less fit, exacerbating the risk for certain physical diseases including cardiovascular disease, colon cancer, and type-2 diabetes (DHHS & DOE, 2000). Unfortunately, recent trends in school policy have minimized physical activity opportunities from the school day to provide additional classroom time on formal academic topics (Thomas, 2004), despite a growing database indicating the benefits of physical activity to cognitive and scholastic performance (Castelli, Hillman, Buck, & Erwin, 2007; see CDC, 2010 for review). Counter to intuition, engaging less classroom time in favor of more physical activity time might improve cognition and learning (Sallis, 2010). That is, a sedentary lifestyle during childhood not only influences physical health but cognitive and brain health as well. Specifically, accumulating evidence has revealed that low levels of physical activity and aerobic fitness are associated with declines in academic achievement, cognitive abilities, brain structure, and brain function (Castelli et al., 2007; Chaddock et al., 2010a, 2010b; Hillman et al., 2008, 2009; Pontifex et al., 2011; Sibley & Etnier, 2003). In older adults, it has been well-established that aerobic fitness relates to improvements in cognitive functions (Colcombe & Kramer, 2003).

Relative to children, recent event-related potential (ERP) studies have supported the positive relation of cardiorespiratory fitness with neurocognitive function in preadolescent children (Hillman et al., 2005, 2009; Pontifex et al., 2011). In addition to these interesting findings, a review of early behavioral studies has suggested that school age children also may derive cognitive benefits from physical activity participation (Sibley & Etnier, 2003). More recently, a review of the longitudinal studies with children indicated improved cognitive performance following participation in physical activity training (Tomporowski et al., 2008). Based on previous studies, several aspects of cognition have elucidated its relation with aerobic fitness in children, such as cognitive control, attention, perceptual motor skills, visual-motor coordination, and academic performance (Sibley & Etnier, 2003; Tomporowski et al., 2008). However, given that the study of physical activity to brain health and cognition is in its infancy, our knowledgebase regarding several areas of study remains limited. To the best of my knowledge, temporal dynamics has not been examined to link the relation of aerobic fitness with cognition in preadolescent children (or individuals of any age). Therefore, a better understand of this relationship may occur through the using of the attentional blink (AB) paradigm.

The Attentional Blink

In general, individuals often fail to receive conscious knowledge of all stimuli arriving simultaneously from multiple sources (Shapiro et al., 1997). For instance, while watching a basketball game, you might not notice that the person sitting beside you is no longer there, even though he walked in front of you as he left. As such, cognitive psychologists attribute this lapse in awareness of seemingly obvious stimuli to temporary losses in attention (Shapiro et al., 1997). These limits governing the brain's ability to process sequentially presented stimuli have been well demonstrated by a deficit that occurs in the rapid serial visual presentation (RSVP) paradigm. In this paradigm, sequential stimuli such as letters, digits, words and pictures are presented briefly in the same location and in rapid succession, at rates of approximately 10 items per second. This paradigm requires participants to identify one (single task) or two (dual task) of these stimuli (the targets) embedded within a stream of distractors. Under the dual task, most participants show a deficit − an attentional blink (AB) − in reporting T2 when presented within half a second after T1 (see Martens & Wyble, 2010 for review). This dual-task condition under the RSVP paradigm, known as the AB paradigm, originates from a paper by Chun and Potter (1995). Based on this classic research, the AB paradigm has been widely used to study the time course of attention. Figure 1a depicts the AB paradigm, in which stimuli are sequentially presented in the middle of the screen. The temporal interval or lag between T1 and T2 is varied systematically. Participants are asked to give their response after presentation of the stream, at their own pace, so that additional interference effects arising from speeded response are avoided (Martens & Wyble, 2010). Of interest, is the response accuracy of T2 from trials in which T1 was accurately identified (denoted as T2|T1).When participants are instructed to ignore the T1, T2 is usually accurately identified regardless of the lag between T1 and T2 (Raymond et al., 1992). However, participants often fail to report/identify T2 when it is presented within 200 − 500 ms after T1, whereas when the interval is longer, T2|T1 recovers (see Figure 1b). Accordingly, the AB is considered a result of attending to T1 and consolidating it into working memory (Chun & Potter, 1995), rather than a perceptual deficit. It might be noticed that T2|T1 is not impaired when the lag between T1 and T2 is 100 ms (denoted as Lag1), which has been termed “lag-1 sparing” (Potter, Staub, & O’Connor, 2002). Given that the cognitive account for the lag-1 sparing is beyond the scope of the present study, the mechanism is not discussed herein. Regardless, given that the temporal dynamics of attention refers to how attention recovers overtime once it has been allocated to a stimulus (Raymond et al., 1992), the AB paradigm has been successful for cognitive researchers to better understand the mechanisms and processes of deploying attention across time and may reveal the temporal limits of the deployment of selective attention (see Dux & Marois, 2009; Martens & Wyble, 2010; Shapiro et al., 1997 for review).

Central Capacity Limitation of the Attention Blink

To date, the precise adaptive significance behind the AB remains unclear. In recent years, the mechanism underlying the AB has been studied as a topic of intense debate following a variety of important publications that have challenged many of the established theories regarding this field (Dux & Marois, 2009). Thus far, there is no single account which can completely explain this complex phenomenon. However, prevalent explanations of the AB stress limited-capacity resources as the major cause of the attentional lapse. On the one hand, the AB has been attributed to retrieval interference between items in working memory (Interference Theory; Raymond, Shapiro, & Arnell, 1995; Shapiro et al., 1994). In this model, Shapiro and colleagues (1994) argued that when a RSVP stream is presented, initial perceptual representations are established for each stimulus. These representations are compared with selection templates (generated from the task instructions), and those stimuli that most closely match are selected and registered in visual working memory. Shapiro et al. (1994) suggested that once in this store, each item is assigned a weighting based on the available space and its similarity to the template. In this model, it is posited that items interfere with one another as retrieval processes are undertaken during presentation of the target (Dux & Marois, 2009). In addition, the AB generally occurs when two targets appear within a short lag (also referred to as stimulus onset asynchrony [SOA]). Accordingly, Shapiro and colleagues (1994) proposed that due to the limited capacity of working memory, T2 receives a diminished weighting, leaving it more susceptible to interference from the other items in the store and, therefore, reducing the likelihood of its being reported (Shapiro et al, 1994; also see Dux & Marois, 2009 for review).

On the other hand, another prevalent limited-capacity resources model suggests that the major cause of AB is failure in consolidating items into working memory (Two-stage Model; Chun & Potter, 1995). According to this model, two stages of stimulus processing are assumed. Specifically, during the first stage, which is assumed to have an unlimited capacity, stimuli are processed to the point of conceptual representation. In the second stage, however, limited capacity attentional processes are needed to consolidate the representations into a durable and reportable form. Thus, the AB is believed to occur because T1 consumes the majority of the attentional resources, preventing the consolidation of T2 (Chun & Potter, 1995).

The main difference between the two-stage model and the interference model is that the former assumes that T2 fails to reach working memory, whereas in the latter it is proposed that T2 enters working memory but is lost due to interferences with T1 (Vogel et al., 1998). Despite differences in the theoretical underpinnings of the AB, these available accounts share the assumption that processing T1 leads to the occupation of certain attentional mechanism that prevent the processing of T2 until T1 processing is completed (Chun & Potter, 1995; Shapiro et al., 1997). Further, a number of researchers have suggested that a combination of the mechanisms described above provides the most complete account of the AB (Vogel et al., 1998; Maki, Couture, Frigen, & Lien, 1997a; Maki, Frigen, & Paulson, 1997b; Shapiro et al., 1997b).

First, this combined model proposed the existence of two processing stages, with stimuli first being conceptually processed before being selected to undergo capacity-limited encoding into visual working memory. Whether stimuli are selected for extended processing after their semantic representations are activated is determined by how closely they match target templates (Dux & Marois, 2009). Second, due to interference between stimuli during preliminary conceptual processing, distractor items that appear in close temporal proximity to T2 are often incorrectly consolidated. Taken together, both a bottleneck in working memory and interference between the conceptual representations of stimuli are hypothesized to give rise to the AB (Dux & Marois, 2009). Based on this model, supportive findings are derived from convergent behavioral evidence (Maki et al., 1997b; Martens et al., 2002; Potter et al., 2005; Shapiro et al., 1997a; Visser et al., 2005) and neuroimaging studies (Luck et al., 1996; Marois et al., 2004; Nueuwenhuis et al., 2005; Pesciarelli et al., 2007; Rolke et al., 2001; Sergent et al., 2005). For instance, blinked T2s (referred to unreported T2s) were found to induce electrophysiological activity associated with semantic processing (Luck et al., 1996). Accordingly, a variety of studies share a high degree of convergence in suggesting that all items that are presented in a stream of information are fully processed up to the point of conceptual representations. In sum, the AB is considered a deficit in consolidating T2 into a reportable working-memory representation arising from a capacity-limited second stage of processing that is tied up with the consolidation of T1 (Martens & Wyble, 2010).

Neural Correlates of Attention Blink

Although available accounts of the AB (i.e., Chun & Potter, 1995) have linked the effect to capacity limitations of working memory, the deployment of brain imaging techniques and patient studies can further provide information to conceptualize AB-related processing limitations towards a neurocognitive model of the AB. In general, research has focused on understanding what brain regions are involved in the AB and this effort has been considered an interactive network of areas consisting of lateral-frontal (for the processing and maintenance of goals and target specifications), infero-temporal (for target identification), posterior-parietal (for target selection), and occipital (for extraction of stimulus characteristics) brain regions, suggested to be associated with the dynamics of attentional selection and processing that causes the AB (see Hommel et al., 2006; Martens & Wyble, 2010 for review). For instance, functional magnetic resonance imaging (fMRI) refers to a neuroimaging technique that measures changes in blood flow thought to support neural activity. Previous studies using fMRI have observed reduced activity in the fronto-parietal cortex (anterior cingulate, lateral prefrontal, and parietal regions in particular) when T2 is not reported (Kranczionch, Debener, Schwarzbach, Goebel, & Engel, 2005; Marchntoni, Lepage, Beaudoin, Bourgouin, & Richer, 2003; Marois et al., 2004), even though both targets successfully activated representations in early visual areas, such as V1 (Williams, Visser, Cunninton, & Mattingley, 2008). In addition, transcranial magnetic stimulation (TMS) is a noninvasive method that produces a transient disruption of cortical function by rapidly changing magnetic fields. Studies using TMS have implicated an important role of the intraparietal sulcus (Cooper, Humphreys, Hulleman, Praamstra, & Georgeson, 2004; Kihara et al., 2007), suggesting causal evidence for the involvement of a brain region underlying the AB paradigm. Importantly, regarding the role of the frontal cortex in the AB, it may be conceived of as the maintenance of task goals requiring the provision of functional top-down support (see Hommel et al., 2006 for review), given that the activation of the lateral-frontal cortex has been associated with selection problems induced by temporally close distractors (Marois et al., 2000) or competing targets (Feinstein et al., 2005; Marcantoni et al., 2003; Moris et al., 2004). For instance, increased activation of the anterior cingulate cortex in the AB task was associated with success in detecting a temporally close T2 (Gross et al., 2004; Marois et al., 2000, 2004). In addition, patient studies have indicated that patients with brain lesions on the right inferior parietal cortex and lateral frontal cortex have shown a stronger and prolonged AB effect (Husain & Rorden, 2003; Husain et al., 1997). Taken together, some specific brain region may play an important role in AB performance based on previous neuroimaging studies.

The Attentional Blink Magnitude

The AB has been assumed to reflect an inevitable limitation in information processing, given that it cannot be eliminated even with extensive training (Braun, 1998; Maki & Padmanabhan, 1994). However, recent studies have questioned the fundamental nature of the phenomenon. That is, a variety of studies have provided evidence that the magnitude of the AB can be reduced by manipulating the allocation of attentional resources to the T1 or T2 (see Martens & Wyble, 2010 for review). For instance, when T1 requires more processing time, such as when the task is manipulated to make identifying T1 more difficult, a larger AB magnitude was observed (Giesbrecht, Sy, & Lewis, 2009; Martens et al., 2006a; Seiffert & Di Lollo, 1997; Taatgen, Juvina, Schipper, Borst, & Martens, 2009; Visser, 2007a, b). In addition, perceptual, spatial, and temporal cues have been found to effectively manipulate attention during the AB (Martens & Johnson, 2005; Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005). For instance, a smaller AB magnitude has been observed when, prior to each trial, participants were provided information related to the temporal interval between the targets in the upcoming trials (Martens & Johnson, 2005). Based on these findings, some degree of top-down control (driven by one's goals or intentions) over the temporal allocation of attention is thought to be possible (Martens & Wyble, 2010). In addition to the above manipulation of temporal dynamics within participants, there is also significant individual variation in AB magnitude. For example, large individual differences in the AB magnitude have been found, with some individuals persistently showing a large AB (referred to as blinkers), and others showing little AB or even no AB at all (non-blinkers) under identical experimental conditions (Martens & Johnson, 2009; Martens et al., 2009, 2006b; Martens & Valchev, 2009). Intriguingly, no differences have been found in working memory capacity or general intelligence between blinkers and non-blinkers (Martens & Johnson, 2008; but also see Arnell, Stokes, MacLean, & Gicante, 2010; Colzato, Spape, Pannebakker, & Hommel, 2007), which supports the argument that a correlation between working memory and AB magnitude may exist. Regardless, it has been suggested that, instead of structural differences, a major source of individual variability in AB magnitude may lie in "pre-memory" processes, which play a crucial role in determining which stimuli are selected for further processing and memory consolidation (Martens & Johnson, 2008). That is, the AB magnitude may be determined by an allocation policy, which might vary from individual to individuals (Martens & Wyble, 2010).

Accordingly, the examination of individual variability in magnitude has emerged as another promising approach to gain insight into the mechanism underlying the AB. This approach focuses on comparing specific groups of participants that tend to demonstrate varying degrees of AB magnitude. For instance, the AB has been shown to be larger and/or longer for certain special populations such as unilateral neglect patients (Husain & Rorden, 2003; Husain et al., 1997), elderly participants (Geirgiou-Karistianis et al., 2007; Lahar et al., 2001; Maciokas & Crognale, 2003), schizophrenics (Cheung, Chen, Chen, Woo, & Yee, 2002; Li et al., 2002), attention deficit hyperactivity disorder (ADHD) patients (Hollingsworth et al., 2001; Li et al., 2004), Alzheimer's patients (Kavcic & Duffy, 2003), and people with severe symptoms of depression (Rokke, Arnell, Koch, & Andrews, 2002), relative to matched controls. Relative to development, previous studies have found that AB duration is progressively longer across adolescence through the study of 7-, 12-, and 15-year-old children (i.e., Garrad-Cole et al., 2011). Such findings are consonant with the work of Dye and Bavelier (2010), who observed 7-13 year olds needed more time to recover attentional resources than 14-22 year olds. Taken together, a larger or protracted AB magnitude might relate to cognitive deficit or immaturity, resulting from inefficient attentional allocation.

Conversely, an attenuated AB magnitude has been shown after an intervention of intensive mental training (Slagter et al., 2007). Specifically, Slagter and colleagues (2007) conducted a longitudinal study in which participant (range: 22 − 64 years old) underwent an AB task after three months of mental training to examine how it affect the major capacity limits of information processing in the brain (the AB deficit). Results revealed that 3 months of intensive mental training resulted in a smaller AB magnitude. Further, Green and Bavelier (2003) found that intensive action video-game playing can improve attention skills, as reflected by enhanced performance on new cognitive tasks, including the AB task. Specifically, training on action video games enhanced the faster recovery from the AB (a shorter AB duration). Taken together, the AB magnitude might be a useful index of the temporal resolution of visual attention to examine group differences as a function of lifestyle, health factors, cognitive aging, and child development.

Event-Related Brain Potentials

P3

Beyond the assessment of overt actions, ERPs provide a means to gain insight into the mechanisms of the processes of cognition and cognitive operations, such as distinct cognitive processes of stimuli (i.e., T1, T2, and distractors) presented in the AB paradigm. Accordingly, these measures allow for a more precise understanding of the temporal dynamics allocated during the RSVP stream. By using specific cognitive tasks with ERPs recording, researchers are able to better understand the neural activity underlying certain aspects of cognition. In general, ERPs are a class of neuroelectric activity that occurs in response to, or in preparation for, a stimulus or response (Coles, Gratton, & Fabiani, 1990). According to their direction and the relative time that they occur, the stimulus-locked ERP is characterized by a succession of positive (P) and negative (N) components (Hruby & Marsalek, 2003). N1 and P2 are earlier components of the stimulus-locked potential related to aspects of selective attention, while N2 and P3 are later components relate to endogenous aspects of cognitive function (e.g., response inhibition, attentional resource allocation).

In the present context, the P3 component (known as P300 or P3b), is of particular interest, since this component is generally observed as a neuroelectric correlate of processes associated with attentional resource allocation (Polich, 2007). The P3 is a positive-going component observed in the stimulus-locked ERP waveform, thought to represent the updating of working memory once sensory information has been processed (Donchin, 1981). As such, the P3 is believed to be generated when one discriminates between stimuli in their environment. Specifically, the amplitude of P3 refers to the amount of attentional resources that have been allocated to a given stimulus when working memory is updated (Donchin & Coles, 1988), such that the P3 is sensitive to the allocation of attentional resources during stimulus engagement (Polich, 2007). Technically, P3 amplitude is measured as the change in voltage from a pre-stimulus baseline to the largest positive peak from 300 to 800 ms following the onset of the stimulus. Further, the latency of P3 is believed to reflect stimulus identification and classification speed. P3 latency is measured from stimulus onset to the maximum peak in a given latency window (Polich & Kok, 1995; Polich, 2004), and has been found to be independent of response selection and action (Verleger, 1997; Duncan-Johnson, 1981).

P3 and the Attentional Blink

Previous investigations using ERPs have begun to reveal the neurocognitive processes underlying the AB. That is, given the excellent temporal resolution of ERP methods has been used to disentangling the processing of two separate targets presented in close temporal proximity during the AB paradigm, directly recorded brain-related evidence has been an important part of our understanding of the AB (Dell'Acqua et al., 2003; Luck et al., 1996; Martens et al., 2006a, 2006b; Pesciarelli et al., 2007; Rolke et al., 2001; Sergent et al., 2005; Vogel et al., 1998). EPR data from multiple studies have converged on a coherent picture of the time course of cognitive processes involved in the AB (see Martens & Wyble, 2010 for review). That is, previous researchers using ERPs have found that a T2 presented during the AB time window (i.e., a short target lag) elicited a normal pattern of neural correlates for at least the first 150 ms of perceptual processing (reflected in the P1 and N1 components; Vogel et al., 1998), but these processed targets failed to elicit the attentional selection response that would normally be observed about 200 ms after stimulus onset (N2pc, an ERP component associated with the allocation of attention to a relevant target; Dell'Acqua, Sessa, Jolicoeurm & Robitaille, 2006; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006a; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006b). Further, this T2 also failed to elicit a P3 component, which is associated with working memory consolidation and attentional resource allocation (Luck et al., 1996; Martens et al., 2006b; Vogel & Luck, 2002; Vogel et al., 1998). Intriguingly, even though this blinked T2 was not fully consolidated, it nevertheless activated semantic representations, as indexed by the N400 component (Luck et al., 1996; Pesciarelli et al., 2007; Rolke et al., 2001; Vogel et al., 1998).

Accordingly, these ERP studies have supported behavioral reports (Maki et al., 1997; Martens et al., 2002; Potter et al., 2005; Shapiro et al., 1997; Visser et al., 2005), suggesting that the AB occurs at a late stage of processing , after early perceptual and conceptual representations have been formed.

In addition to the neuroelectric measures of the T2, recent studies have focused on T1-elicited ERP components. Given that several leading models/theories (i.e., Chun & Potter, 1995; Shapiro et al., 1994) of AB have commonly claimed that there is a capacity-limited stage in stimulus processing, the P3 component has been examined as an index of the distribution of limited brain resources. That is, due to the major capacity limits of information processing in the brain: the brain's limited ability to process two temporally close meaningful items, the AB performance might be associated with brain resource allocation to the first target, such as the T1-elicited P3 component (Slagter et al., 2007). Previous ERP studies found that the ability to accurately identify T2 is related to the latency and/or amplitude of the T1-elicited P3 (Martens et al., 2006a, 2006b; Sergent et al., 2005; Shapiro et al., 2006; Slagter et al., 2007). Specifically, Sergent and colleagues (2005) using ERPs in an AB paradigm found that, relative to the trials when T2 was blinked, the T1-elicited P3 amplitude was slightly smaller in trials when T2 was reported. Further, with regard to the relationship between the T1-elicited P3 component and AB magnitude, a T1-elicited P3 with smaller amplitude (Shapiro et al., 2006) or shorter latency (Martens et al., 2006b) has been observed in people who exhibited a relatively smaller AB magnitude, suggesting a greater ability to allocate limited resources or identify targets more rapidly, which may lead to an earlier consolidation of relevant information. Taken together, these finding indicated that T1-elicited P3 may reflect the level of competition between T1 and T2. Therefore, as described above, there is significant individual variation in AB magnitude.

However, it is plausible that ERP studies using T1-elicited P3 might reinforce that individual variation in AB magnitude might reflect the differences in the T1-elicited P3 component, suggesting the possibility of using this component to examine groups of participants with different levels of AB magnitude.

Thus far, to the best of my knowledge, only two AB studies have used ERP methods to compare specific groups of participants (Martens et al., 2006b; Slagter et al., 2007). First, Martens and colleagues (2006b) using ERPs, measured attentional resources distribution for blinkers and non-blinkers during execution of an AB task. Here, some individuals referred to as non-blinkers (approximately 5% of the population) showed little or no AB effect (see Martens et al., 2006b for definition). Results showed that non-blinker exhibited a shorter T1-elicited latency than blinkers, suggesting that non-blinkers were indeed faster than blinkers to consolidate T1. Second, Slagter and colleagues (2007) conducted a longitudinal study using performance in an AB task and ERPs to examine the effect of three months mental training on the distribution of limited brain resources underlying the AB paradigm. Results revealed that three months of mental training exhibited an attenuated AB and reduced brain-resource allocation to T1, as reflected by decreased T1-elicited P3 amplitude (Slagter et al., 2007). They suggested that the ability to accurately identify T2 might depend upon the efficient deployment of resources to T1 and further concluded that mental training may facilitate increased control over the distribution of limited brain resources. Taken together, studying P3 components might be a useful tool to gain insight into neural correlates of the time course of temporal dynamics during the AB paradigm.

The Relationship between Neurocognitive Function and Aerobic Fitness

As previously described, several factors have been associated with temporal dynamics of selective attention, including lifestyle (i.e., Slagter et al., 2007), cognitive decline (Geirgiou-Karistianis et al., 2007; Lahar et al., 2001; Maciokas & Crognale, 2003), and mental health (i.e., Li et al., 2004; Hollingsworth et al., 2001; Husain & Rorden, 2003; Husain et al., 1997). This relation has been extended through the inclusion of ERPs, such that T1-elicited P3 amplitude has been used as a tool to investigate the time course of attentional resources allocation (Martens et al., 2006b; Slagter et al., 2007). Intriguingly, recent studies have suggested that physical activity and cardiorespiratory fitness are associated with not only chronic diseases prevention, but also neurocognitive function (i.e., attentional resources allocation) across the lifespan (see Hillman et al., 2008 for review). Thus, an interesting question has arisen: Does aerobic fitness have a positive association with temporal dynamics reflected in P3-related changes and the AB magnitude? Based on the existing literature on both temporal dynamics and aerobic fitness on neuroelectric indices of cognitive processes (the latter of which will be discussed below), an overview of studies using ERPs to examine the relationship between fitness and cognition will be discussed in order to provide justifications for the present investigation.

Recently, a positive relation of aerobic fitness with neurocognitive function across the lifespan has been established (see Hillman et al., 2008; Kramer & Hillman, 2006 for review). This relation has been extended into children populations (Hillman et al., 2009; Hillman et al., 2005; Potifex et al., 2011). However, as described in the beginning of this chapter, only certain aspects of cognition have been extensively investigated since the study of cognition and fitness is in its infancy. It is noted that Kramer and colleagues (1999) first reported that increased aerobic fitness selectively improved performance on tasks requiring greater amounts of cognitive control. Specifically, one of the components found to improve in Kramer et al.'s (1999) study was attentional control, a distributed neural network supporting attentional function (Hasher & Zacks, 1998), suggesting that attention is closely involved in the relationship between fitness and cognition. Further, a growing amount of ERP researchers have focused on the examination of the selective effects of fitness on cognitive control over the past decade. As such, to provide a clearer picture of the relationship between aerobic fitness and neurocognitive functions with a particular focus on ERP indices of cognitive control, I will first describe the concept of cognitive control and then review the extant findings of fitness and cognition related to child population.

Cognitive control refers to an overarching set of higher-order, cognitive operations, which are associated with the regulation of goal-directed interactions within the environment (Botvinick; Carter, Braver, Barch, & Cohen, 2001; Meyer & Keiras, 1997; Norman & Shallice, 1986). These processes allow individuals to optimize their behavior through the selection, scheduling, coordination, and maintenance of computational processes underlying aspects of perception, memory, and action (Botvinick et al., 2001; Meyer & Keiras, 1997; Miyake et al., 2000; Norman & Shallice, 1986). Cognitive control has been thought to include subtypes of cognitive functions including inhibition of attention and action, working memory, and cognitive flexibility (Diamond, 2006). Cognitive control is dependent upon the functional maturation of a network involving the frontal brain regions and in particular the prefrontal cortex (Adleman et al., 2002; Casey, Galvan, & Hare, 2005; Fassbender et al., 2004; Rubia et al., 2000, 2006; Rubia, Smith, Taylor, & Brammer, 2007; Tamm, Menon, & Reiss, 2002).

Given that the study of exercise to brain health and cognition is in its infancy, a few ERP studies have suggested that preadolescent fitness might be positively related to cognitive control (Hillman et al., 2005; 2009; Pontifex et al., 2011). That is, the relationship between exercise and neuroelectric indices of cognition in children still requires further examination. In younger and older adults, aspects of cognition have been found to be sensitive to physical activity (Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Hillman, Kramer, Belopolsky, & Smith, 2006; McDowell, Kerick, Santa Maria, & Hatfield, 2003; Polich & Lardon, 1997; Themanson, Hillman, & Curtin, 2006) and aerobic fitness (Dustman et al., 1990; Emmerson, Dustman, Shearer, & Turner, 1989; Hillman, Weiss, Hagberg, & Hatfield, 2002). Based on these findings, greater physical activity or fitness has been shown to be associated with larger P3 amplitude and/or decreased P3 latency, suggesting increased allocation of neural resources and faster processing speed, respectively. With respect to children, a relatively smaller literature has explored the relationship of fitness to cognition. However, a few studies have emerged to support for the importance of fitness during cognitive development (Hillman et al., 2005; 2009; Pontifex et al., 2011). Specifically, Hillman and colleagues (2005) used an oddball task, which requires attention and working memory to compare the P3 component between higher-fit and lower-fit children (mean age = 9.6 years). Results revealed that higher-fit children may be able to recruit a greater amount of attentional resources toward the stimulus environment and process information more quickly, as reflected by larger P3 amplitude and shorter P3 latency, along with better task performance compared to their lower-fit counterparts. Next, Hillman and colleagues (2009) extended their initial findings by examining 9-10 year old children through the use of a modified flanker task (Eriksen & Eriksen, 1974). This task requires variable amounts of attentional control for successful task completion. They found that higher-fit children exhibited more accurate responses and larger P3 amplitude compared to lower-fit children across task conditions. These findings were replicated in Pontifex et al. (2011), as they observed overall larger P3 amplitude in higher-fit children through a manipulation of stimulus-response compatibility (i.e., cognitive flexibility) during a flanker task. Collectively, these ERP studies using a variety of cognitive tasks suggested that aerobic fitness may promote better cognitive and brain health through improvements in the allocation of attentional resources, reflecting by increased P3 amplitude and/or shorter P3 latency.

Purpose

Given that aerobic fitness has been found to positively relate to aspects of cognition in which the AB paradigm requires (i.e., attentional resource distribution, working memory); this study intends to employ neuroelectric and behavioral measures to examine the relationship between aerobic fitness and temporal dynamics of selective attention in preadolescent children. Specifically, this study seeks to understand whether aerobic fitness influences the attentional blink magnitude and neuroelectric indices of attentional resource allocation. Preadolescent children with different levels of aerobic fitness (i.e., lower-fit children versus higher-fit children) will be implemented for comparison purposes.

Rationale

Despite these seemingly disparate bodies of literature, there are some striking similarities between the aspects of cognition that are related to aerobic fitness and those which exhibit AB-related deficits. However, to date, no prior research has investigated the relationship between aerobic fitness and AB in children or adults. Thus, the study proposed herein may provide additional insight into the relation of aerobic fitness to temporal dynamics and indicate that higher amounts of aerobic fitness may benefit cognitive health and effective functioning during preadolescent maturation. If a significant relationship exists between aerobic fitness and temporal dynamics in children, these findings may support the benefit of physical activity and exercise as a means for improving the cognitive health. It was hypothesized that higher-fit children would exhibit a relatively attenuated AB magnitude, smaller T1-elicited P3 amplitude, shorter T1-elicited P3 latency, smaller T2-elicited P3 amplitude, and shorter T2-elicited P3 latency compared to lower-fit children. This finding would indicate that higher-fit children have better temporal dynamics as reflected by better task performance and more efficient attentional resources distribution toward task relevant information (i.e., T1 and T2), as well as faster cognitive processing speed than lower-fit children. Such a pattern of results would suggest that aerobic fitness is beneficial to cognitive processes that support the temporal dynamics of attention, and have implications for promoting better brain health and effective functioning of school age children.

CHAPTER 3

METHODOLOGY

The relationship between aerobic fitness and temporal dynamics in preadolescent children was investigated. A sample of 44 preadolescent children was recruited from the East Central Illinois area. Each participant underwent the cardiorespiratory fitness assessment and cognitive tasks during the completion of the two day experiment.

Participants and Recruitment

Preadolescent children between the ages of 9 and 10 years from the East Central Illinois area were recruited to participate via advertisements. Participants' cardiorespiratory fitness was defined based on their maximal oxygen consumption (VO2max). Initially, a total of 58 potential participants who were interested in this study were initially screened based on the number of days per week they participated in organized youth sports activities. From this screening, a total of 49 participants who participated more than four days or less than two days were invited to the laboratory for aerobic fitness testing to determine whether they were qualified for the study (i.e., classified into the higher- or lower-fit group) based on their VO_2 max scores. Based on the VO_2 max test, 44 qualified participants were bifurcated into higher- (VO_2 max scores above the 70^{th} percentile) or lower- (VO_2 max scores below the 30^{th} percentile) fitness groups based on age-specific norms (Shavartz & Reibold, 1990). One higher-fit and 4 lower-fit participant were excluded due to poor task performance in the dual-target condition (Mean T2|T1 = 18.5%), which did not allow for examination of neuroelectric indices due to an insufficient number of trials. Thus, analyses were conducted on 39 participants (19 higher-fit; 20 lower-fit). All participants and their legal guardians provided written informed assent/consent in accordance with the Institutional Review Board of the University of Illinois at Urbana-Champaign (see

Appendix B and C). Data were collected on several factors that have been associated with either physical activity participation or cognitive function. Specifically, all participants were administered the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990) by a trained experimenter to obtain a composite IQ scores using measures of crystallized (vocabulary) and fluid (analogies) thinking. Next, participants completed the Eidenburgh Handedness Inventory (Oldfield, 1971) to determine hand dominance (see Appendix D). Socioeconomic status (SES) was determined using a trichotomous index based on three variables: participation in free or reduced-price lunch program at school, the highest level of education obtained by the mother and father, and number of parents who worked full-time (Birnbaum et al., 2002). Given that temporal dynamics has been found to be differently allocated under training of the action video games (Green & Bavelier, 2003), it is important to access screen time variables in order to monitor the potential influence of temporal dynamics in the current study. Table 1 lists demographic and fitness information for the final sample.

Exclusionary Criteria

Non-consent of the child or the guardian resulted in exclusion from the investigation. In addition, a guardian of the child completed the Attention-Deficit/Hyperactivity Disorder (ADHD) Rating Scale IV (DuPaul, Power, Anastopoulos & Reid, 1998) to screen for the presence of attentional disorders. Any participant who scores exceeded the 85th percentile (which would suggest the presence of ADHD) was excluded from the investigation. Next, any participant outside of the 9-10 year old age range was not included given that previous research (e.g., McGivern, Andersen, Byrd, Mutter, & Reilly, 2002) has suggested that pubertal timing may be related to performance on cognitive tasks, thus allowing for too much variability in the sample. To ensure that all study participants were in the earliest stages of puberty or have not yet begun pubertal changes, any participant with a score greater than 2 on the modified Tanner Staging Scales (Taylor et al., 2001; see Appendix E) was excluded. For their safety, any participant who was not capable of performing exercise based on the Physical Activity Readiness Questionnaire (PAR-Q; Thomas, Reading, & Shephard, 1992; see Appendix F) and/or Health History & Demographics Questionnaire (see Appendix G) was excluded from the investigation. Similarly, participants had normal or corrected to normal vision, were free of any adverse health conditions, neurological disorders, and any medications that influence central nervous system function.

Power Analysis

An *a priori* power analysis was conducted to estimate the appropriate sample size necessary for detecting an effect of fitness on T1-elicited P3 amplitude, accounting for the inclusion of potentially confounding variables (i.e., age, sex, IQ, and SES). An effect size was calculated using previously collected cross-sectional ERP data from our laboratory (Pontifex et al., 2011) on the relation of aerobic fitness to P3 amplitude in healthy preadolescent children. Specifically, Pontifex et al. (2011) observed that higher-fit children exhibited increased P3 amplitude (M=10.5 μV, SD=3.92) relative to lower-fit children (M=7.2 μV, SD= 3.92) resulting in a large effect size (Cohen's d = 0.84). Therefore, assuming this effect size (Cohen's d = 0.84), two-sided alpha of .05, and beta of .20 (i.e., 80% power), a minimum sample size of 19 participants per group should yield a final sample with adequate power. Accordingly, with participant attrition and potential issues associated with ERP data collection, testing 44 participants yielded a final sample size of 39 participants (20 lower-fit, 19 higher-fit), which should be appropriate to achieve adequate power.

Cardiorespiratory Fitness Assessment

Maximal oxygen consumption (VO_2max) was measured using a computerized indirect calorimetry system (ParvoMedics True Max 2400) with averages for oxygen uptake (VO_2) and respiratory exchange ratio (RER) assessed every 20 seconds. A modified Balke protocol (ACSM, 2010) was employed to measure children's cardiorespiratory fitness given that this protocol is recommended and suitable for undertaking graded exercise testing with children (ASCM, 2010). Specifically, a motor-driven treadmill was administrated at a constant speed with increases in grade increments of 2.5% every two minutes until volitional exhaustion. To measure the participant's heart rate (HR), a Polar heart rate monitor (Polar WearLink®+ 31, Polar Electro, Finland) was used throughout the test. In addition, ratings of perceived exertion (RPE) were assessed every two minutes using the children's OMNI scale (Utter, Roberson, Nieman, & Kang, 2002). The children's OMNI scale for RPE indicates a numerical scale from 0 to 10, with a score of 2 indicating "a little tired" and a score of 9 indicating "very, very tired", with associated pictographs representing perceived physical effort. Relative peak oxygen consumption was expressed in ml/kg/min and will be based upon maximal effort as evidenced by 1) a plateau in oxygen consumption corresponding to an increase of less than 2 ml/kg/min despite an increase in workload; 2) a peak heart rate $\geq$ 185 bpm (ACSM, 2010) or a heart rate plateau (Freedson & Goodman, 1993); 3) RER $\geq$ 1.0 (Bar-Or, 1983); and/or 4) ratings on the children's OMNI scale of perceived exertion $\geq$ 8 (Utter et al., 2002).

Attentional Blink Task

The present study used a modified attentional blink paradigm with the same experimental settings and methodology as those used by Slagter et al. (2007). Stimuli were presented in white on a black background at the center of a computer screen. The AB task consisted of identifying two numbers (Targets; referred to as T1 and T2) in a rapid serial visual presentation (RSVP) stream of letters (Distractors). Before each trial, a fixation cross was presented for 1780ms in the middle of the screen, followed by the RSVP stream consisting of 15 or 19 stimuli. Each stimulus was presented for 50 ms, followed by a 34-ms interstimulus-interval. On each trial, each letter (the distractor) was randomly drawn (without replacement) from the alphabet (except B, I, O, Q, and S). Relative to targets, one (single-target task) or two (dual-target task) of the letters were replaced with a number, randomly drawn (without replacement) from 2 – 9. When only one letter was replaced by a number, a second letter was replaced with a blank screen (referred as single-target trials or T2-absent trials). In T2-present trials (or dual-target trials), the temporal distance between T1 and T2 was short (336ms, referred to as Lag 4) or long (672ms, referred to as Lag 8). These specific lags were chosen on the basis of the literature and previous work (Slagter et al., 2007). Specifically, T2 was likely to be "blinked" (i.e., not identified) at Lag 4, whereas little or no reduction in T2 accuracy was usually observed at Lag 8. T2 and the blank screen were presented at temporal position 3-5 from the end of the stream.

Participants were informed that there could be one or two numbers in the letter stream, and 1,000 ms after the stream ended, then were asked to report these numbers into a microphone. Participants were instructed to guess T2 if they thought that T2 had been presented, but were not entirely sure of its identity. If they were absolutely sure that no T2 was presented, they answered "none" for this number. A new trial began 200 ms after the second response. After a short practice block (composed of 15 trials), participant performed four blocks of 102 trials each, consisting of 192 short-interval (Lag 4) dual-target trials, 72 long-interval (Lag 8) dual-target trials, 72 short-interval (Lag 4) single-target trials, and 72 long-interval (Lag 8) single-target trials, all intermixed within blocks. Behavioral data were collected on T2 response accuracy (i.e., number of correct and error responses) for Lag 4 and Lag 8 across task blocks. The AB magnitude was measured on T2 accuracy given a correctly identified T1 (denoted as T2|T1). Stimulus presentation, timing, and measurement of behavioral response accuracy were controlled by Neuroscan Stim (v 2.0) software.

Neuroelectric Assessment

Participants were prepared for neuroelectric assessment in accordance with the guidelines of the Society for Psychophysiological Research (Picton et al., 2000). Electroencephalographic (EEG) activity was recorded from 64 Ag-AgCl electrode sites (FPz, Fz, FCz, Cz, CPz, Pz, POz, Oz, FP1/2, F7/5/3/1/2/4/6/8, FT7/8, FC3/1/2/4, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, P7/5/3/1/2/4/6/8, PO7/5/3/4/6/8, O1/2) arranged in an extended montage based on the International 10-10 system (Chatrian, Lettich, & Nelson, 1985) using a Neuroscan Quik-cap (Compumedics, Inc, Charlotte, NC). A midpoint between Cz and CPz was used as referenced sites during recording, with AFz serving as the ground electrode, and impedance less than 10kΩ. Additional electrodes were placed above and below the left orbit and the outer left and right canthi to monitor electrooculogram (EOG) activity with bipolar recording. Continuous data were digitized at a sampling rate of 500 Hz, amplified 500 times with a DC to 70 Hz filter, and a 60 Hz notch filter using a Neuroscan Synamps2 amplifier (Neuro, Inc., Charlotte, NC, USA).

Procedure

A cross-sectional design had participants visit the laboratory on two separate days (less than 1 week apart) in which they had not previously participated in physical education or other structured physical activities.

Day 1.

Upon arrival to the laboratory, a detailed explanation of the purpose of the research and its potential risks was provided and participants were given the opportunity to ask questions prior to obtaining informed written assent from the participant and consent from their legal guardian acknowledging their understanding of the potential risks, that they were under no obligation to participate in the study, and that they may withdraw from the study at any time without penalty. Following completion of the informed consent/assent, participants completed the Edinburgh Handedness Inventory (Oldfield, 1971) and the K-BIT (Kaufman & Kaufman, 1990). Concurrently, participants' legal guardians completed the Physical Activity Readiness Questionnaire (Thomas et al., 1992), the modified Tanner Staging System questionnaire (Taylor et al., 2001), the ADHD Rating Scale IV (DuPaul et al., 1998), and a health history and demographics questionnaire. Upon the completion of all questionnaires, participants then were briefed as to the purpose of the fitness assessment and the Children's Omni Ratings of Perceived Exertion Scale (Utter et al., 2002) was explained. Children were given an orientation to the treadmill and mouthpiece, as well as provided an opportunity to practice with each prior to the aerobic fitness test using the modified Balke protocol described earlier.

Those children who fell into one of the two fitness groups, had no symptoms that would preclude them from exercising, a normal health history, an IQ score greater than 85, and score a 2 or below on the Tanner staging scale qualified and were invited to participate in the second day of cognitive testing. This session took an hour and participants were paid $10 for their participation.

Day 2.

Upon arrival to the laboratory, participants were outfitted with an electrode cap and provided task instructions. Specifically, after the preparation of the electrode cap, participants were seated in a sound attenuated testing chamber and given the task instructions prior to each task condition. Forty practice trials were provided and participants' performance was checked before the initiation of testing. When all task conditions were completed, participants were briefed on the purpose of the experiment, and received $10/hour for their participation.

ERP Reduction

Offline EEG processing included EOG correction with a spatial filter (Compumedics Neuroscan, 2003). Specifically, the spatial filter procedure initially involved the creation of an average artifact file from the original continuous data file. This file marked blink artifacts in the bipolar vertical EOG channel (VEOG) and created an average of this blink activity. This average file was then subjected to a spatial singular value decomposition (SVD) analysis that performed a Principle Component Analysis (PCA) to determine the major components that characterized the covariance matrix of the blink activity between all channels. A second SVD analysis was conducted on an artifact-free block of original data to identify the major components associated with legitimate EEG activity across all channels. Finally, the spatial filter transform was applied to the original data file with the parameters set to remove the artifact components from the first SVD analysis, but retained the EEG components identified in the second SVD analysis. This transform reconstructed all of the original channels without the unwanted blink artifacts while maintaining the EEG activation.

Following EOG correction, neuroelectric processing including re-referencing to average mastoids, creation of stimulus-locked epochs (-200 to 1600 ms relative to T1 onset), baseline removal (-200 ms proceeding to T1; Slagter et al., 2007), low-pass filtering (20 Hz; 24dB/octave), and artifact rejection (epochs with signal that exceeded ± 75μV will be rejected) were completed. Artifact-free waveforms in which both targets were correctly indentified (i.e., no-blink trails) were averaged. On Lag 4 trials, T1-elicited P3 components were evaluated as the largest positive-going peak within a 350 to 650 ms latency window while T2-elcited P3 components were evaluated as the largest positive-going peak within a 900 to 1100 ms latency window (Slagter et al., 2007). On Lag 8 trials, T1-elicited P3 components were evaluated as the largest positive-going peak within a 350 to 650 ms latency window while T2-elcited P3 components were evaluated as the largest positive-going peak within a 1200 to 1400 ms latency window (Slagter et al., 2007). Amplitude was measured as the difference between the mean prestimulus baseline and maximum peak amplitude; peak latency was defined as the time point corresponding to the maximum amplitude. Each participant's data were then output in ASCII format for statistical analyses using IBM SPSS 19.0.

Statistical Analysis

All statistical analyses were conducted using a significance level of p=.05. Prior to hypothesis testing, preliminary analysis was conducted to ensure that the higher-fit and lower-fit groups did not significantly differ on any factors known to influence cognitive function in this age group (e.g., SES, age, pubertal timing, sex, video-game playing, etc.). Task performance of dual-target trials (including T1 accuracy and the AB magnitude; T2|T1), were submitted to a separate 2 (Fitness: Higher-fit, Lower-fit) × 2 (Lag: Lag 4, Lag 8) multivariate repeated measures ANOVAs. T1 accuracy on single-target trials were also submitted to a 2 (Fitness: Higher-fit, Lower-fit) × 2 (Lag: Lag 4, Lag 8) multivariate repeated measures ANOVA. The P3 components (i.e., T1-elicited P3 amplitude, T1-elicited P3 latency, T2-elicited P3 amplitude, T2-elicited latency) were assessed separately using 5 midline electrode sites for amplitude and latency using a 2 (Fitness: Higher-fit, Lower-fit) × 2 (Lag: Lag 4, Lag 8) × 5 (Site: Fz, FCz, Cz, CPz, Pz) multivariate repeated measures ANOVA. Post hoc comparisons were conducted using Bonferroni corrected *t* tests.

CHAPTER 4

RESULTS

The results section is organized by dependent measure. First, participant characteristics are reported in relation to fitness groupings. Second, the behavioral measures associated with task performance (T1 accuracy and the AB magnitude; T2|T1) are reviewed. Next, analyses of the neuroelectric components are provided (T1-elicited P3, T2-elicited P3), with amplitude presented first followed by latency within each component.

Participant Characteristics

Participant demographics and fitness data for all participants are provided in Table 1. No significant differences between groups were observed for age, pubertal timing, IQ, SES, and time spent playing video games, *t's*(37) ≤ 1.7, *p* ≥ .19; with the exception of fitness level including both VO_2max scores, *t*(37) = 10.9, *p* < .001, and VO_2max percentile, *t*(37) = 41.6, *p* < .001 (see Table 1), confirming the efficacy of the participant matching procedure.

Task Performance

Figure 2 depicts the overall task performance collapsed across groups for each task condition. All participants exhibited decreased T2 accuracy (T2|T1) on Lag 4 relative to Lag 8, whereas all participants exhibited equal T1 accuracy across lags, confirming the efficacy of the AB paradigm. Table 2 provides mean (SD) values for behavioral measures as a function of task condition.

T1 accuracy on single-target trials

No main effects or interactions involving Fitness or Lag were observed for T1 accuracy, *F*'s (1,37) ≤ 1.5, *p* ≥ .56, $\eta_p^2 \leq 0.04$ (see Figure 3.A).

T1 accuracy on dual-target trials

No main effects or interactions involving Fitness or Lag were observed for T1 accuracy, *F*s (1,37) $\leq$ 2.0, $p \geq .80$, $\eta_p^2 \leq 0.05$ (see Figure 3.B).

T2 accuracy on dual-target trials

Analyses revealed a significant Lag effect, $F(1,37) = 43.1$, $p < .001$, $\eta_p^2 = 0.54$, with decreased T2 accuracy (T2|T1) for Lag 4 (54.7 ± 1.8 %) relative to Lag 8 (65.1 ± 2.3 %) trials. Further, a main effect of Fitness was observed, $F(1,37) = 9.0$, $p = .005$, $\eta_p^2 = 0.20$, with decreased T2 accuracy (T2|T1) for lower-fit (54.2 ± 2.7 %) relative to higher-fit (65.6 ± 2.7 %) participants. These effects were superseded by a Fitness × Lag interaction, $F(1,37) = 6.\ 8$, $p = .013$, $\eta_p^2 = .16$. Decomposition of the Fitness × Lag interaction revealed decreased T2 accuracy (T2|T1) for lower-fit participants (47.0 ± 2.7 %) relative to higher-fit participants (62.4 ± 2.3 %), only for the Lag 4 trials, $t(1, 37) = 4.3$, $p < .001$ (see Figure 3.C), suggesting that lower-fit children exhibited a larger AB magnitude compared to higher-fit children.

Event-related Brain Potentials

Figure 4 illustrates the grand average stimulus-locked ERP waveforms at 5 midline electrode sites (Fz, FCz, Cz, CPz, Pz) for each fitness group and lag. In addition, Figure 5 illustrates topographic plots of P3 amplitude for each fitness group and task condition. Table 3 provides mean (SD) values for neuroelectric measures as a function of task condition.

T1-elicited P3

Amplitude

Analysis of T1-elicited P3 amplitude revealed a main effect of Fitness, $F(1,37) = 8.1$, $p = .007$, $\eta_p^2 = 0.18$, with increased T1-elicited P3 amplitude for lower-fit (7.8 ± 0.6 μV) relative to higher-fit (5.3 ± 0.6 μV) participants (see Figure 6.A). A main effect of Site was also observed, $F(4,34) = 49.0$, $p < 0.001$, $\eta_p^2 = 0.85$, with smaller T1-elicited P3 amplitude at Fz relative to all other electrode sites, t's$(38) \geq 8.2$, $p \leq .001$; at FCz relative to the Cz and CPz electrode sites [t's$(38) \geq 2.4$, $p \leq .01$]; and at CPz relative to the Pz electrode site [$t(38) = 0.68$, $p = .01$]. No effect of Lag was observed, $F(1,37) = 0.3$, $p = .57$, nor did any variable interact, F's$(4,34) < 1.2$, $p > .74$.

Latency

No main effects or interactions involving Fitness, Lag or Site were observed for T1-elicited P3 latency, F's $(1,37) \leq 1.8$, $p \geq .08$, $\eta_p^2 \leq 0.11$.

T2-elicited P3

Amplitude

Analysis of T2-elicited P3 amplitude revealed a main effect of Fitness, $F(1,37) = 5.4$, $p = .025$, $\eta_p^2 = 0.13$, with increased T2-elicited P3 amplitude for lower-fit (15.7 ± 1.5 μV) relative to higher-fit (10.7 ± 1.5 μV) participants (see Figure 6.B). A main effect of Site was also observed, $F(4,34) = 55.9$, $p < 0.001$, $\eta_p^2 = 0.87$, with smaller T2-elcited P3 amplitude at Fz relative to all other electrode sites, t's$(38) \geq 8.5$, $p \leq .001$; and at FCz relative to the Cz, CPz, and Pz electrode sites [t's$(38) \geq 7.3$, $p \leq .001$].

Latency

Analysis of T2-elicited P3 latency revealed a main effect of Lag, $F(1,37) = 529.5$, $p < .001$, $\eta_p^2 = 0.94$, with increased latency for Lag 8 (1262.3 ± 9.9 ms) relative to Lag 4 trials (992.8 ± 14.4 ms). A main effect of Site was also observed, $F(4,34) = 48.6$, $p < 0.001$, $\eta_p^2 = 0.85$, with the shortest T2-elcited P3 latency at Fz relative to all other electrode sites, t's$(38) \geq 10.5$, p

$\leq .001$; and at FCz relative to the Cz electrode site [$t(38) \geq 44.7$, $p < .001$]. These effects were superseded by a Lag × Site interaction, $F(4,34) = 3. 4$, $p = .019$, $\eta_p^2 = .29$. Decomposition of the Lag × Site interaction revealed shorter latency at Lag 4 relative to Lag 8, at all midline sites, $t(38) \geq 9.2$, $p < .001$.

CHAPTER 5

DISCUSSION

This study examined whether aerobic fitness was associated with one of the major capacity limits of information processing in the brain: the brain's limited ability to process two temporally close meaningful items in the environment. The key finding of this study suggested that fitness was positively related to temporal dynamics in preadolescent children, providing novel evidence for the notion that children who are aerobically fit are more likely to exhibit better behavioral and neuroelectric indices of performance in tasks requiring temporal resolution of visual attention. Specifically, children with a higher level of aerobic fitness were found to exhibit a relatively attenuated AB magnitude (i.e., greater T2|T1 accuracy) compared to lower-fit children. In addition, neuroelectric findings revealed that higher-fit children exhibited overall smaller P3 amplitude across task conditions relative to lower-fit children. Accordingly, the results suggest that aerobic fitness might serve to facilitate increased control over the distribution of limited brain resources. Thus, these data support the relation of aerobic fitness to the temporal dynamics of visual attention and indicate that higher amounts of aerobic fitness may benefit cognitive and brain health, and effective functioning during preadolescent maturation. Given that a significant relationship was found to exist between aerobic fitness and temporal dynamics in children, these findings provide support for the benefit of physical activity as a means for improving the cognitive health and function.

Task Performance

Consistent with previous investigations, all child participants exhibited a deficit, an attentional blink (see Martens & Wyble, 2010 for review), which refers to reduced accuracy of reporting the identity of T2 when it occurs 200 − 500 ms after T1, whereas T2|T1 recovers when the lag increases (Chun & Potter, 1995; Raymond et al., 1992; Shapiro et al., 1994). Replicating previous findings (Slagter et al., 2007), all participants, regardless of fitness level, exhibited decreased T2|T1 accuracy at Lag 4, relative to Lag 8. Novel to this investigation, however, was the application of the AB task in healthy preadolescent children. Applying a modified attentional blink paradigm with the same experimental settings and methodology as those used by Slagter et al. (2007), the current study extended their findings and found that children, as young as 9 years of age, display a similar pattern as typically seen in adults. Consistent with previous studies examining children (Dye & Bavelier, 2010; Garrad-Cole et al., 2011), the current results indicated decreased response accuracy (T2|T1) at Lag 4 relative to Lag 8, confirming that the AB task might be a useful index of the temporal resolution of visual attention to examine cognitive development in children.

It is important to point out that a previous study (Heim, Wirth, & Keil, 2011) examined developmental changes in temporal dynamics using a cross-sectional design. Heim and colleagues (2011) observed that older children (10- to 11-year-olds) successfully displayed a typical pattern of AB-related deficit, whereas younger children (6- to 7-year-olds) did not, suggesting that the control of attention allocation and/or working memory consolidation of targets among distractors represents a cognitive skill that emerges between these periods of development. Accordingly, the current study sample aged 9 – 10 years exhibiting a typical pattern of AB-related deficits might support the argument of Heim et al. (2011). Hence, future research is necessary to examine temporal dynamics focusing on pediatric populations, given the paucity of data that exists in the literature.

Germane to the focus of this investigation, however, was to determine the extent to which aerobic fitness may be associated with the AB performance within specific task conditions. As expected, the current study revealed differences in the AB magnitude as a function of fitness, with higher-fit children exhibiting a smaller AB magnitude relative to lower-fit children. Specifically, current results indicated that higher-fit children exhibited a greater T2|T1 accuracy only at Lag 4, suggesting that aerobic fitness has a positive association with behavioral indices of temporal dynamics. That is, this fitness-related difference on temporal dynamics was not found for T1 accuracy or T2|T1 at Lag 8. Accordingly, a selective relation of fitness to behavioral indices of temporal dynamics was found, particularly within the AB task condition (i.e., T2|T1 accuracy at Lag 4) requiring efficient attentional resources distribution, working memory encoding, episodic registration, response selection, enhancement of target representations, and inhibition of distractors (see Dux & Marois, 2009 for review). Thus, these findings add to a growing body of research demonstrating that aerobic fitness is beneficial for cognitive development in preadolescent children (Castelli et al., 2007; Chaddock et al., 2010a, 2010b; Hillman et al., 2008, 2009; Pontifex et al., 2011; Sibley & Etnier, 2003), and suggest that the beneficial relation of fitness may be extended to different domain of cognitive functioning (i.e., temporal dynamic of attention). Taken together, the AB magnitude may be a useful tool to examine the relationship between fitness and temporal dynamics in preadolescent children.

Interestingly, it is important to note that previous non-fitness studies have found individual variability in the AB magnitude. That is, temporal dynamics has been found to be allocated differently as a function of lifestyle or health factors (Green & Bavelier, 2003; Martens et al., 2006b; Slagter et al., 2007). With regard to non-fitness-induced enhancement in temporal dynamics, intensive mental training (Slagter et al., 2007) and action video-game playing (Green & Bavelier, 2003) have been found to facilitate an attenuated AB magnitude. For instance, Slagter and colleagues (2007) conducted a longitudinal study and found that 3 months of intensive mental training resulted in a smaller AB magnitude. Further, similar improvement was found after intensive action video-game playing (Green & Bavelier, 2003). Taken together, it is possible that the temporal dynamics might be “shaped” based on demographic, lifestyle or health factors, as reflected by a smaller attention-blink size (i.e., the AB magnitude).

With regard to the current study, temporal dynamics as a function of fitness was examined in preadolescent children, with results indicating that aerobic fitness may facilitate the development of temporal dynamics during earlier periods of the lifespan by reflecting an attenuated AB magnitude. Given that the control of attention allocation and/or working memory consolidation of targets among distractors represents a cognitive skill that emerges during childhood (Dye & Bavelier, 2010; Garrad-Cole et al., 2011; Heim et al., 2011), aerobic fitness may facilitate these cognitive processes during cognitive development. Indeed, a growing database has indicated a beneficial relationship between physical activity/aerobic fitness to preadolescent cognition including academic achievement, cognitive functioning, brain structure, and brain function (Castelli et al., 2007; Chaddock et al., 2010a, 2010b; Hillman et al., 2008, 2009; Pontifex et al., 2011; Sibley & Etnier, 2003). With that in mind, being aerobically fit and active might be a successful means to improve temporal dynamics relative to video-game playing or mental training, given that physical activity/aerobic fitness can also improve physical health (i.e., prevention of cardiovascular disease, colon cancer, type-2 diabetes, etc.; see DHHS & DOE, 2000 for review).

Event-Related Brain Potentials

Within the application of neuroelectric indices of the temporal dynamics, this study further examined whether aerobic fitness was related to one of the major capacity limits of information processing in the brain: the brain’s limited ability to process two temporally close meaningful items. Specifically, a more precise understanding of the relationship between aerobic fitness and temporal dynamics may be provided through the assessment of the specific component processes that underlie the AB paradigm. One neuroelectric potential, which has been extensively studied and been found sensitive to both AB-related deficits, and exercise-induced enhancements, is the P3 component. Along with better task performance (i.e., smaller AB magnitude), the current study found that higher-fit children exhibited reduced attentional resource allocation to the first target at Lag 4, as reflected by a smaller T1-elicited P3 amplitude within the AB time window. That is, higher-fit children might perform better in detecting the T2 (i.e., an attenuated AB magnitude at Lag 4) through the reduction or titration of brain-resource allocation to T1. Given that 1) the ability to accurately identify T2 depends upon the efficient deployment of resources to T1; and 2) the AB-related deficits results from suboptimal resource sharing (Martens et al., 2006b; Shapiro et al., 2006; Slagter et al., 2007; Vogel et al., 1998; Sergent et al., 2005), current results suggest that higher level of aerobic fitness might facilitate increased control over the distribution of limited brain resources. Indeed, with regard to the relationship between the T1-elicited P3 component and AB magnitude, a T1-elicited P3 with smaller amplitude (Shapiro et al., 2006) or shorter latency (Martens et al., 2006b) has been observed in people who exhibited a relatively smaller AB magnitude, suggesting a greater ability to allocate limited resources or identify targets more rapidly, which may lead to an earlier consolidation of relevant information. Together, recent findings may indicate a positive relationship between aerobic fitness and the ability to allocate limited attentional resources.

Novel to the present investigation, however, was the assessment of fitness-induced modulations in both T1- and T2-elicited P3 components in children. Findings revealed that higher-fit children exhibited reduction for both T1- and T2-elicited P3 amplitude relative to lower-fit children. To date, this is the only study examining the relationship between fitness and temporal dynamics. Given that no existing research has examined the relationship between fitness and the temporal dynamics, it is necessary to compare the neuroelectric data collected herein with existing ERP-related studies that have examined non-exercise induced enhancements in temporal dynamics.

First, the findings reported herein do not reflect the same pattern observed by Slagter and colleagues (2007) who observed enhancements in AB magnitude and reduction in T1-elicited P3 amplitude (no significant reduction observed in T2-elicited P3 amplitude) following 3 months of intensive mental training. However, as mentioned above, fitness might improve attentional resources distribution underlying a specific neural mechanism, resulting in the disparity in the observed between the current data and those of Slagter et al. (2007). Further, a number of methodological factors might also be responsible for the discrepancy observed within the present investigation. For instance, a mental training intervention (i.e., meditation; Slagter & colleagues, 2007) investigated the change in temporal dynamics after mediation training and found that the training-induced reduction was not observed for T2-elicited P3 amplitude, suggesting that intensive mental training might selectively reduced brain-resource allocation to T1 (Slagter et al., 2007). Slagter and colleagues (2007) argued that meditation may reduce ongoing mental noise in the brain, enabling individual to reduce mental capture by any stimulus, including distracters and targets alike (Martens et al., 2006b), resulting in reduced distracter interference (Slagter et al., 2007). Accordingly, it is possible that meditation and fitness might improve temporal dynamics through different mechanisms within the brain.

Second, with regard to the relationship between fitness and the P3 component, recent neuroelectric studies using ERPs have supported a positive relation of aerobic fitness with neurocognitive function across the lifespan (see Hillman et al., 2008; Kramer & Hillman, 2006; Hillman, Kamijo, & Pontifex, 2011, for review). In children, several studies have employed the P3 to assess the fitness–cognition relationship, suggesting a general improvement in the allocation of attentional resources toward external events in the stimulus environment (Hillman et al., 2009; Pontifex et al., 2011). Specifically, Hillman and colleagues (2009) using a modified flanker task to assess attentional control found that higher-fit children exhibited more accurate responses and larger P3 amplitude across task conditions compared to lower-fit children, suggesting that greater fitness is related to a better efficiency in the allocation of attentional resources during stimulus evaluation. Similar results were observed by Pontifex and colleagues (2011), with higher-fit children exhibiting overall larger P3 amplitude across task conditions. Accordingly, findings from these cross-sectional studies (Hillman et al., 2009; Pontifex et al., 2011) suggest that higher preadolescent fitness may improve cognitive functioning through overall improvements in the allocation of attentional resources that support goal-directed behavior. Given that aerobic fitness has been found to positively relate to aspects of cognition in which the AB paradigm requires (i.e., attentional resource distribution), as expected, the current study employing neuroelectric and behavioral measures found that higher level of aerobic fitness attenuated the AB magnitude and efficiently reduced neuroelectric indices (i.e., P3 amplitude) of attentional resource allocation. Collectively, the flexible allocation of attentional resources observed in higher-fit individuals might imply changes in the neuronal activity as a function of aerobic fitness. For instance, P3 amplitude is increased in certain circumstances (e.g., such as those that support attentional control) and reduced in other circumstances (such as those that support the temporal dynamics of attention). That is, the commonality across aspects of attention is the capability of more fit individuals to flexibly titrate or optimize resources to meet the demands of the task. Accordingly, the current findings suggest that higher-fit children might have greater temporal dynamics through the flexible allocation of attentional resources to meet the time sensitive nature of the task.

Lastly, the current study found that aerobic fitness may modulate the P3 component elicited by T2; findings from this investigation revealed a general, yet selective, relation of fitness to the P3 components. Specifically, larger T2-elicited P3 amplitude was observed, indicating more diffuse activation for lower-fit children relative to higher-fit children. The P3 amplitude is thought to be proportional to the amount of attentional resources devoted to a given stimulus or task. With regard to the relationship between task performance and P3 amplitude, lower-fit children exhibited overall increased T2-elicited amplitude, along with larger AB magnitude (reflected as decreased T2|T1 accuracy). These results might indicate that lower-fit children may have greater difficulty in distributing attentional resources, with excessive recruitment of neural resources and an inefficiency of top-down control to meet the challenges imposed by the AB task. In addition, the attentional blink deficit is thought to occur due to limitations in capacity, such that each stimulus competes for a limited pool of attentional resources. That is, greater T2-elicited P3 amplitude may reflect a relatively inefficient attentional resources distribution given the limited brain resources underlying the AB paradigm. As mentioned above, aerobic fitness may serve to facilitate the distribution of attentional resources by reflecting reductions in P3 amplitude during the AB task. With that in mind, given the AB-related deficit is thought to occur due to competition between the two targets for limited attentional resources (Shapiro et al., 1997), difficulty in consolidating T2 into a reportable working-memory representation (Martens, Wolters, & Van Raamsdonk, 2002; Rolke, Heil, Streb, & Henninghausen, 2001; Vogel et al., 1998; Luck, Vogel, & Shapiro, 1996), and the failure of inhibition of task-irrelative distractors (see Dux & Marois, 2009 for review), it is possible that higher-fit participants may relatively successfully distribute attentional resources through the reduction in capturing both targets relative to lower-fit participants.

Another possibility may account for the different pattern observed in the current results relative to previous fitness-related ERP studies (Hillman et al., 2005; 2009; Pontifex et al., 2011). Specifically, previous studies have used stimulus discrimination tasks (i.e., flanker tasks, Go-NoGo tasks) to examine a different domain of cognitive function (i.e., cognitive control). In such tasks, Polich (1990) posits that P3 amplitude decreases with high target probability at short inter-stimulus-interval (ISI) because the processing system is not fully recovered from the previous component generation when the next target stimulus is presented. Accordingly, the direction of P3 amplitude is sensitive to the type of cognitive tasks and the temporal dynamics of the paradigm. Given that the relatively shorter ISI in the current RSVP paradigm, is it possible that higher-fit children exhibited economy of information processing relative to lower-fit children to prepare for the second target (T2), reflected in overall smaller P3 amplitude. However, future research is necessary to better address potential mechanisms to gain insight into the fitness-induced changes in temporal dynamics.

A number of mechanisms that have been identified may account for the observed fitness-related enhancements in temporal dynamics. On the one hand, with regard to the fitness-induced differences in brain structures, Colcombe and colleagues (2004, 2006) have found that aerobic fitness was positively associated with larger volumes of prefrontal and temporal gray matter, as well as anterior white matter (Gordon et al., 2008; Mark et al., 2007) volumes. On the other hand, with regard to the neural correlates of AB, previous studies have indicated that the AB-related deficit is involved with an interactive network of areas consisting of lateral-frontal, infero-temporal, posterior-parietal, and occipital brain regions (see Hommel et al., 2006; Martens & Wyble, 2010 for review). Further, previous studies using fMRI have observed reduced activity in the fronto-parietal cortex (anterior cingulate, lateral prefrontal, and parietal regions in particular) when individuals failed to report T2 (Kranczionch et al., 2005; Marchntoni et al., 2003; Marois et al., 2004). In addition, patient studies have indicated that patients with brain lesions on the right inferior parietal cortex and lateral frontal cortex have shown a stronger and more prolonged AB magnitude (Husain & Rorden, 2003; Husain et al., 1997). Accordingly, it is likely that fitness may alter those brain areas that are involved in the AB, resulting in changes in temporal dynamics.

Limitations

Although the current study reports on relationships among fitness and neuroelectric and behavioral indices of temporal dynamics, there are a number of limitations to the current study. For instance, the cross-sectional nature of this study yields the possibilities that the observed fitness-related differences, may have resulted from other factors. That is, unassessed correlates of fitness may be carrying the observed relationships, rather than fitness per se. However, this possibility was minimized given that data were collected on a number of demographic factors known to influence cognition and fitness, and any relationships between these factors and the dependent measures were examined to help limit other potential influences. In addition, although analyses were able to determine the extent to which fitness was associated with P3 amplitude, as well as AB magnitude, it is important to note that no causal relationships have been proposed herein. Given the early nature of this research, future studies should consider employing randomized control interventions to establish a causal relationship between fitness and temporal dynamics in children. In spite of these limitations, the present data extends fitness and cognition research by suggesting that the AB magnitude and P3 amplitude might be useful tools to examine the relationship between fitness and the maturation of temporal dynamics during preadolescence. Such findings add support for the beneficial relation of fitness to cognitive and brain health and function, and may have implications for scholastic performance.

Conclusion

Although the present investigation can only speculate on the specific patterns of brain activation underlying the observed neuroelectric components, the general influence of fitness on P3 components supports the notion that there is a distinct pattern of cognitive processes for environmental stimuli (i.e., T1, T2) presented in the AB paradigm, and that the various generators for the competition between targets demanding attentional resources are influenced by cardiorespiratory fitness. Considering the relationship between fitness and P3 amplitude across conditions of the AB task, the current pattern of findings suggest that cardiorespiratory fitness is associated with reductions in attentional resource distribution for both targets. Most importantly, fitness appears to moderate the individual variability in the attentional-blink size, with attenuated AB magnitude observed in higher-fit individuals.

In sum, aerobic fitness may facilitate temporal dynamics through efficient allocation of attentional resources. The present findings provide a supportive evidence for further examination of the relationship between aerobic fitness and temporal dynamics in preadolescent children. Further, early physical activity intervention to promote aerobic fitness might be an ideal means of improving not only physical health but cognitive health as well. Given that recent trends in school policy are reducing opportunities for physical activity (e.g., physical education, recess) from the school day to create additional instruction on formal academic subjects (Thomas, 2004), these data speak to the importance of physical activity for the maturation of neural networks underlying aspects of temporal dynamics and have implications for maximizing cognitive health and function in real-world settings during development.

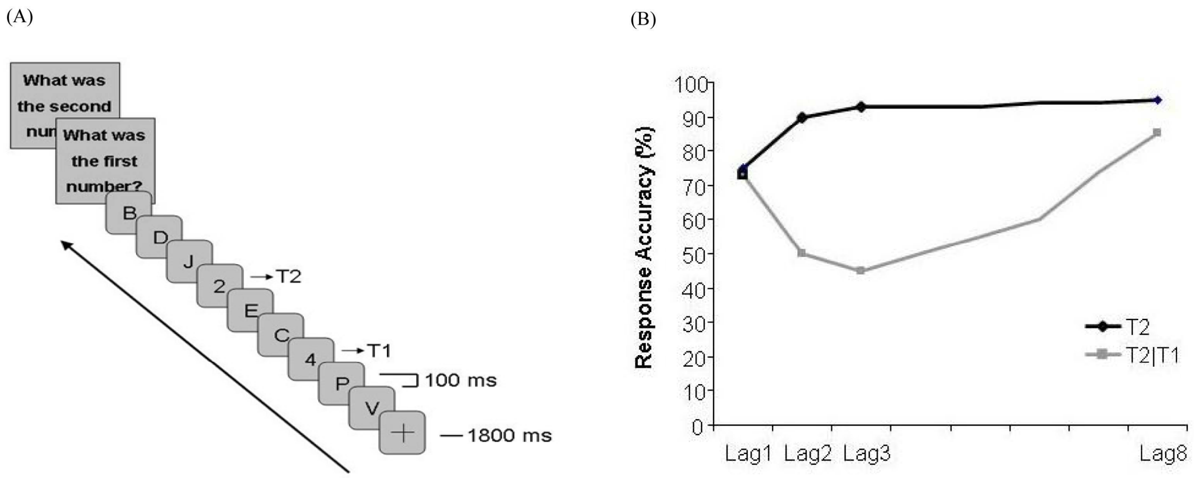

Figure 1. The attentional-blink paradigm.

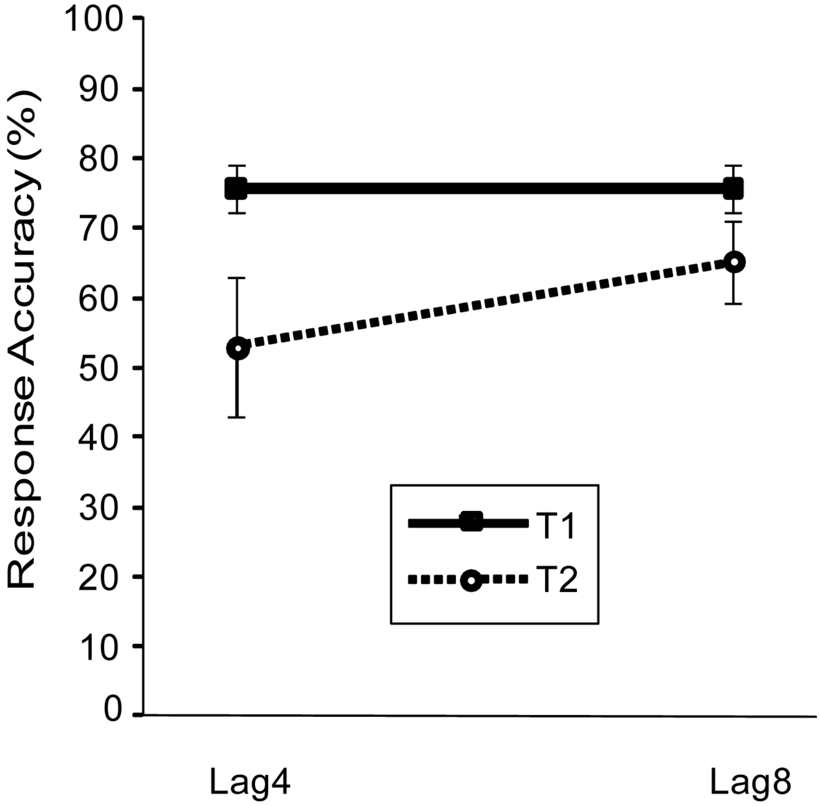

Figure 2. Mean accuracy (± SE) as a function of lag collapsed across fitness groups.

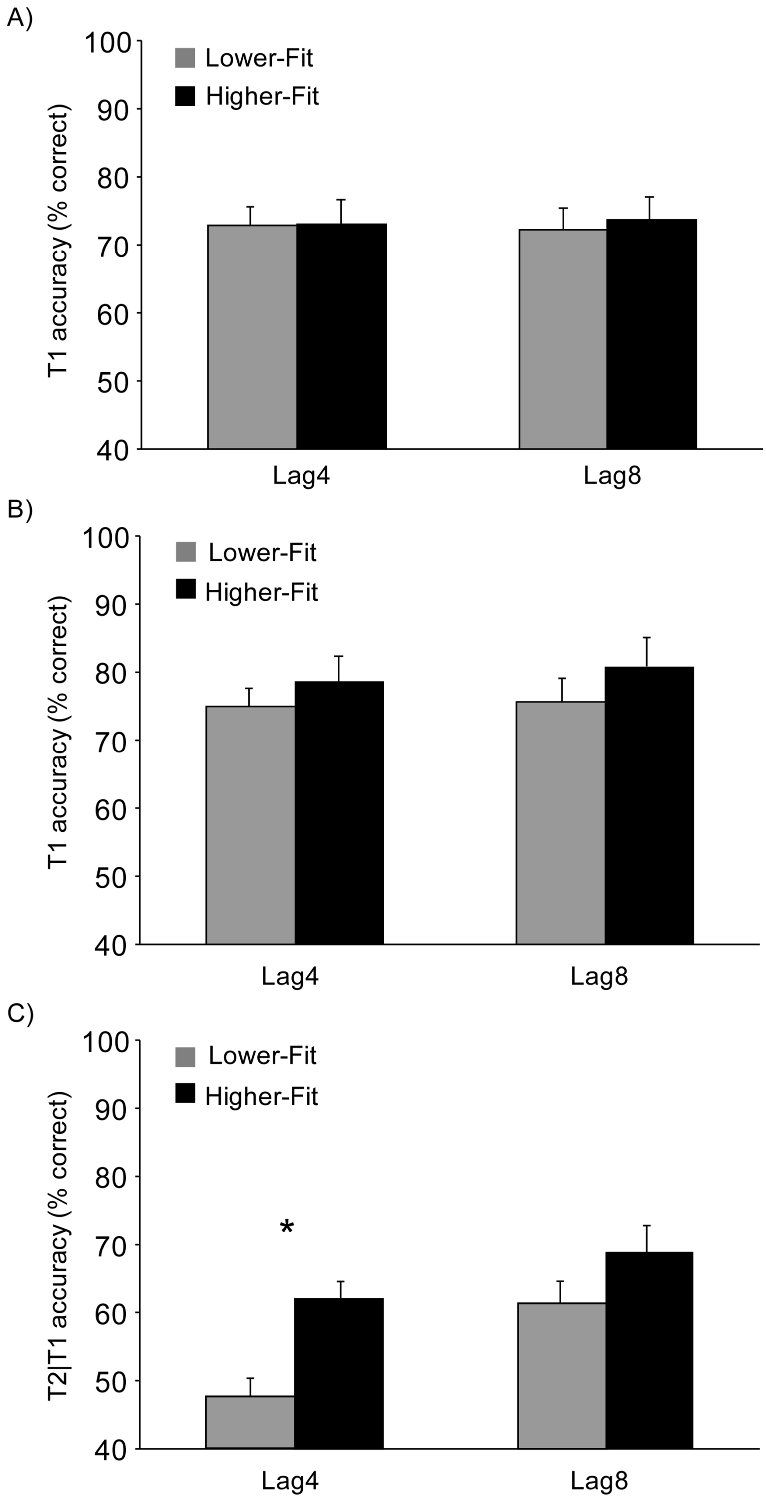

Figure 3. Mean accuracy (± SE) for T1 on single-target trials (A), T1 on dual-target trials (B) and T2 (T2|T1) on dual-target trials (C) for each group by lag.

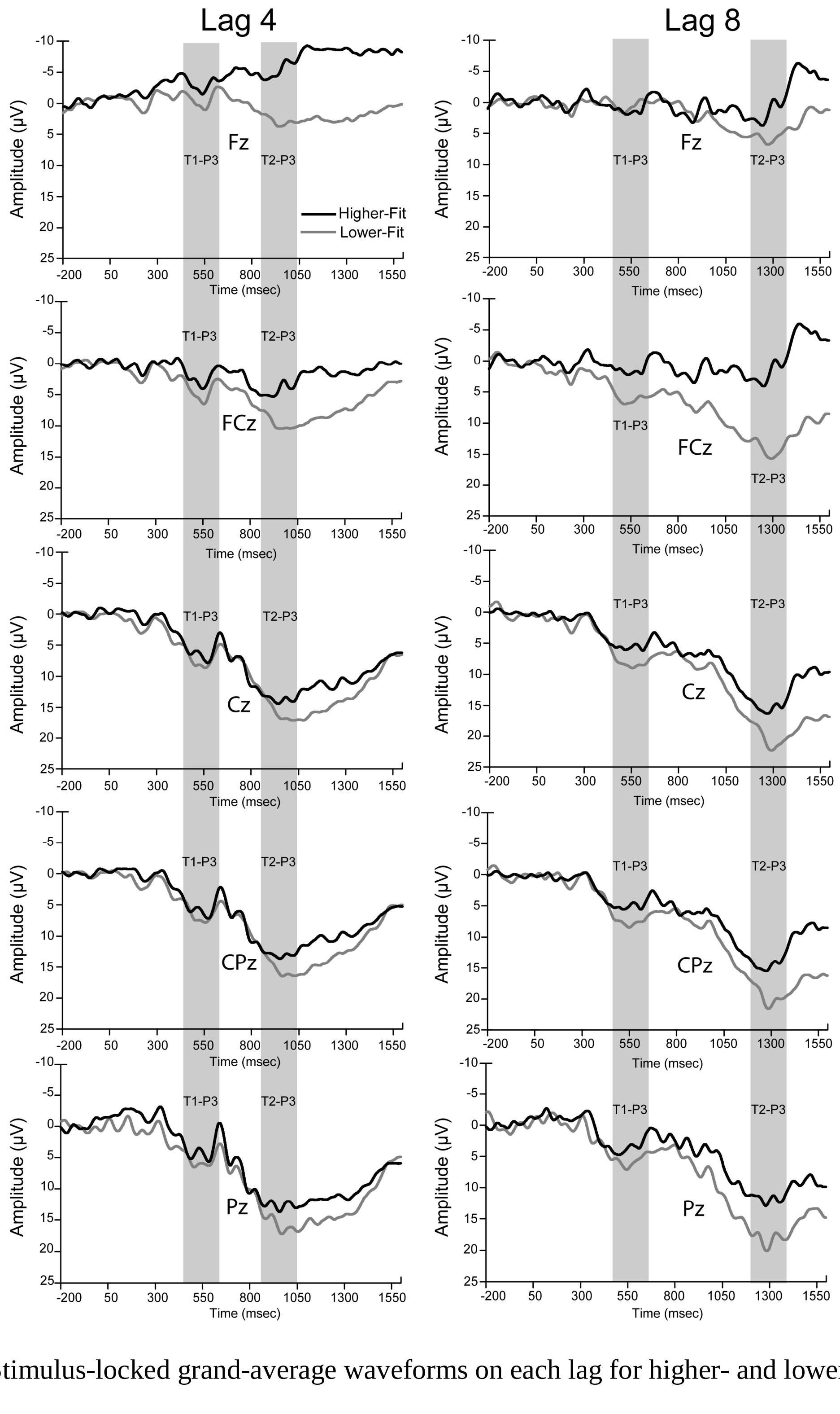

Figure 4. Stimulus-locked grand-average waveforms on each lag for higher- and lower-fit participants.

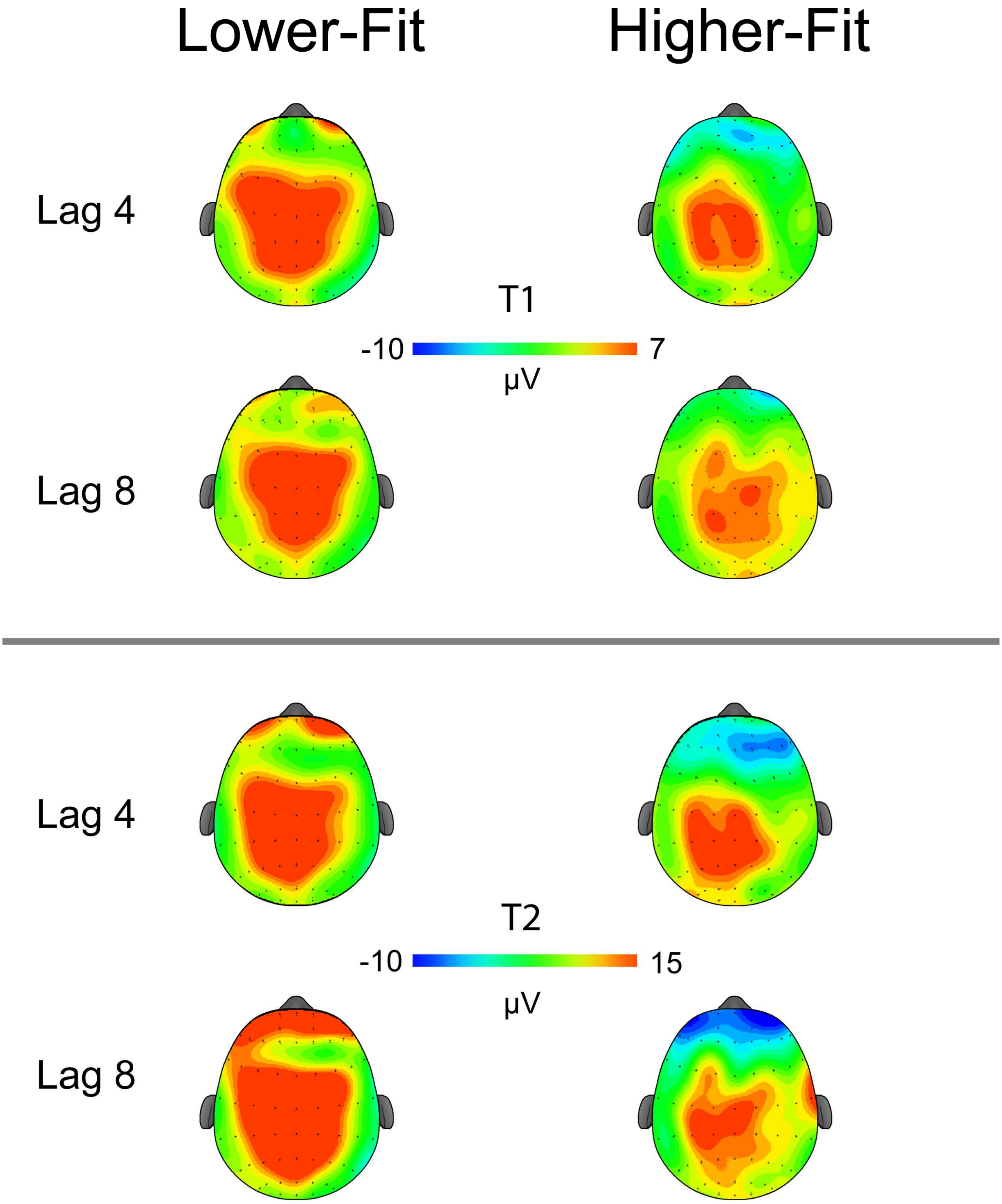

Figure 5. Topographic plots of P3 amplitude for each fitness group and task condition.

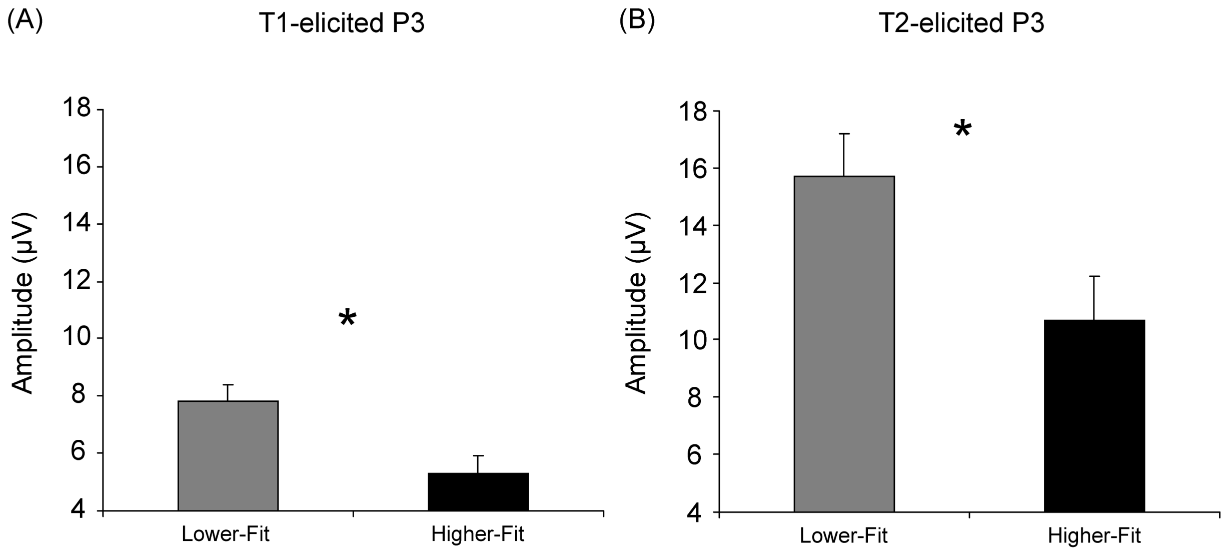

Figure 6. Mean P3 amplitude (± SE) for T1 (A) and T2 (B) for each group across lags and sites.

Table 1.

Participant demographic values (±1 SD)

Measure	Lower-Fit	Higher-Fit
n	20 (11 females)	19 (10 females)
Age (years)	10.1 ± 0.5	10.1 ± 0.4
Tanner	1.4 ± 0.4	1.2 ± 0.4
K-BIT composite (IQ)	113.2 ± 10.9	117.7 ± 10.1
Socioeconomic Status (SES)	2.2 ± 0.8	2.5 ± 0.5
ADHD	6.7 ± 2.9	6.7 ± 3.3
Video-game playing (weekdays)	1.2 ± 0.9	1.1 ± 0.3
Video-game playing (weekends)	1.7 ± 1.4	1.8 ± 0.6
VO_2max (ml/kg/min)	37.0 ± 4.2**	50.4 ± 3.3**
VO_2max Percentile	10.2 ± 6.6**	80.0 ± 3.2**

Note: Tanner- scores indicate that pubertal status was at or below a score of 2 (prepubescent) on the 5-point scale from the Tanner Staging System (Taylor et al., 2001). SES- scores reflect a trichotomous index based on participation in free or reduced-price lunch program at school, the highest level of education obtained by the mother and father, and the number of parents who worked full-time (Birnbaum et al., 2002). Video-game playing reflects how many hours (on average) an individual spends playing during the week and the weekend. ADHD- scores on the Attention Deficit Hyperactivity Disorder Rating Scale IV. VO_2max- maximum oxygen consumption. VO_2max Percentile- scores reflect normative values, based on age and sex for VO_2max (Shvartz and Reibold, 1990). $^{**}p \leq .001$.

Table 2.

Mean (±SD) Values for Task Performance Measures by Task Condition.

Measure	Lag 4	Lag 8
Response accuracy (%) for T1 on single-target trials	72.4 ± 11.4	73.0 ± 13.4
Response accuracy (%) for T1 on dual-target trials	76.5 ± 9.1	78.0 ± 9.7
Response accuracy (%) for T2|T1 on dual-target trials	54.4 ± 13.5	65.0 ± 14.5

Table 3.

Mean (±SD) Values for T1-elicited P3 Components at Each Electrode Site by Task Condition.

Measure	Lag 4	Lag 8
T1-elicited P3 amplitude at Fz	0.6 ± 5.8	1.4 ± 3.9
T1-elicited P3 amplitude at FCz	6.1 ± 3.9	6.3 ± 5.0
T1-elicited P3 amplitude at Cz	9.2 ± 3.3	9.3 ± 4.8
T1-elicited P3 amplitude at CPz	8.5 ± 3.8	8.7 ± 4.7
T1-elicited P3 amplitude at Pz	7.8 ± 3.9	8.0 ± 5.0
T1-elicited P3 latency at Fz	548.2 ± 33.5	544.9 ± 50.2
T1-elicited P3 latency at FCz	542.1 ± 27.9	541.0 ± 43.1
T1-elicited P3 latency at Cz	541.9 ± 34.5	542.1 ± 43.1
T1-elicited P3 latency at CPz	540.9 ± 34.0	544.0 ± 38.8
T1-elicited P3 latency at Pz	547.8 ± 35.0	583.7 ± 36.5

Table 4.

Mean (±SD) Values for T2-elicited P3 Components at Each Electrode Site by Task Condition.

Measure	Lag 4	Lag 8
T2-elicited P3 amplitude at Fz	2.0 ± 10.0	1.6 ± 9.7
T2-elicited P3 amplitude at FCz	9.7 ± 7.7	10.7 ± 10.3
T2-elicited P3 amplitude at Cz	18.7 ± 8.2	19.1 ± 8.7
T2-elicited P3 amplitude at CPz	17.9 ± 8.7	17.8 ± 9.0
T2-elicited P3 amplitude at Pz	18.1 ± 9.3	17.0 ± 12.4
T2-elicited P3 latency at Fz	940.4 ± 121.4	1163.0 ± 134.0
T2-elicited P3 latency at FCz	979.3 ± 111.2	1265.3 ± 78.5
T2-elicited P3 latency at Cz	1026.8 ± 87.5	1307.5 ± 60.8
T2-elicited P3 latency at CPz	1005.2 ± 94.8	1295.4 ± 61.8
T2-elicited P3 latency at Pz	1011.8 ± 113.0	1282.2 ± 81.5

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APPENDIX A: ADHD RATING SCALE IV

Please circle the number that *best describes* your child's home behavior over the last 6 months.

		Never or Rarely	Sometimes	Often	Very Often
1.	Fails to give close attention to details or makes careless mistakes in schoolwork.	0	1	2	3
2.	Fidgets with hands or feet or squirms in seat.	0	1	2	3
3.	Has difficulty sustaining attention in tasks or play activities.	0	1	2	3
4.	Leaves seat in situations in which remaining seated is expected.	0	1	2	3
5.	Does not seem to listen when spoken to directly.	0	1	2	3
6.	Runs about or climbs excessively in situations in which it is inappropriate.	0	1	2	3
7.	Does not follow through on instructions and fails to finish work.	0	1	2	3
8.	Has difficulty playing or engaging in leisure activities quietly.	0	1	2	3
9.	Has difficulty organizing tasks and activities.	0	1	2	3
10.	Is "on the go" or acts as if "driven by a motor."	0	1	2	3
11.	Avoids tasks (e.g. homework) that require sustained mental effort.	0	1	2	3
12.	Talks excessively.	0	1	2	3
13.	Loses things necessary for tasks or activities.	0	1	2	3
14.	Blurts out answers before questions have been completed.	0	1	2	3
15.	Is easily distracted.	0	1	2	3
16.	Has difficulty awaiting turn.	0	1	2	3
17.	Is forgetful in daily activities.	0	1	2	3
18.	Interrupts or intrudes on others.	0	1	2	3

DuPaul, Power, Anastopoulos, & Reid (1998).

APPENDIX B: INFORMED CONSENT FORM

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Department of Kinesiology & Community Health

Louise Freer Hall
906 South Goodwin Avenue
Urbana, IL 61801-3895
217 244-2663 *office*
e-mail: chhillma@illinois.edu
http://www.kch.illinois.edu

"Aerobic Fitness and the Attentional Blink in Preadolescent Children"

Investigator Directing Research: Charles Hillman, Ph.D., University of Illinois at Urbana-Champaign, (217) 244-2663, chhillma@illinois.edu.

You and your child are being invited to participate in a research study about the relationship between exercise and cognitive function. Your child's participation in this project is completely voluntary. In addition to your permission, your child will also be asked if he or she would like to take part in this project. Only those children who have parental permission and who choose to participate will do so. You and your child are free to withdraw your consent to participate and may stop taking part at any time and for any reason without penalty. If you are participating in another study in our lab and you decide not to participate in this study, or withdraw your consent prior to your completion in this study, it will have no effect on your participation in another study. This form is designed to provide you with information about the nature of the procedure and the potential risks and/or benefits of this study in order for you to make an informed decision regarding your participation. If you and your child agree to participate, your child will complete an exercise test, cognitive tasks while connected to an electroencephalogram (EEG), and a number of paper and pencil tests that measure demographic and health information.

Today

As a participant, your child will be asked to complete a questionnaire. This questionnaire is administered by an experimenter and will require your child to look at pictures or read words and indicate their meaning. In addition, you will be asked to complete a health history and demographics questionnaire, a questionnaire that determines your child's readiness to exercise, a physical maturation questionnaire, as well as a questionnaire regarding your child's behaviors. Your child will be given an orientation to the equipment necessary for aerobic fitness testing (i.e., treadmill, mouthpiece, nose-clip), and will then participate in a maximal exercise test, which measures their fitness level by having them walk/run on a treadmill at a vigorous pace. They will have a chance to practice on the treadmill prior to testing. This test should not last longer than 15 minutes, and will be supervised by a minimum of two people who are certified in Cardiopulmonary Resuscitation (CPR) and First Aid. This session will take approximately one hour. You will be paid $10.00 for your child's participation, and you and your child may be asked to participate in one additional session. Should you or your child decide to withdraw participation prior to the completion of the experiment, you will still be compensated the full $10.00 amount.

The Remainder of the Study

If you are asked to return to the lab for a second visit, your child will be asked to complete standard cognitive tasks in front of a computer. During this time, s/he will be seated in a comfortable chair and his/her mental reactions will be recorded through the use of sensors placed on the scalp. The experimenter will explain to your child where these sensors will be placed before s/he attaches them. The sensors are both painless and harmless. They merely record the electrical signals naturally produced by the brain. Sometimes, participants find the cap to be uncomfortable. We will frequently ask if they are experiencing any discomfort. If they are, we will make adjustments to the cap to relieve their discomfort. This process is normal and is typically rectified quickly. The tasks involve watching a series of numbers and letters that will appear on a computer screen in front of him/her. Your child will be asked to press one of two buttons during each trial. This second visit will take approximately 2 hours. You will be paid $10/hour per session for your child's participation (for a total of $20). Should you or your child decide to withdraw participation prior to the completion of the experiment, you will still be compensated the full amount.

Potential Risks and Benefits

Your child's participation in this research will be kept confidential and data will be averaged and reported in aggregate. All data obtained from this study will be used for research purposes only, not for the evaluation or diagnosis of any disorder, and will remain confidential, except as required by law. Although your child's participation in this research may not benefit them personally, findings will contribute to gaining further insight into the relationship between physical activity and cognition. Further, these findings may have implications for lifestyle factors during childhood that relate to improved cognitive health across the lifespan, and may provide a rationale for the development of physical education programs to improve cognitive health and scholastic performance.

All procedures, techniques, equipment, and measures to be used in the study are routinely used in educational and research settings involving human subjects. No individual methodological element is new, untested, or of questionable safety for the health and general well being of human subjects.

It is necessary to inform you that when individuals who have been sedentary engage in exercise, there is a chance of incurring minor discomfort or injury due to the intensified use of major muscle groups that have not received a great deal of use. However, we do not anticipate any major injuries to occur. There is also a very slim chance that sudden death or cardiac irregularities can occur while exercising. As noted, this is very rare and the benefits of exercise are known to outweigh the risks. However, at all times your child will have two or more staff members trained in CPR and First Aid in attendance.

In the event of physical injury resulting from this research study, immediate medical treatment is available from a number of health care providers in the area. However, the University of Illinois does not provide medical or hospitalization insurance coverage for participants in this research study, nor will the University of Illinois provide compensation for any injury sustained as a result of participation in this research study, except as required by law. If at any time, day or night, your child experiences adverse physical symptoms, you should immediately contact your personal physician or emergency personnel (i.e., dial 911).

You will be given a copy of this consent form for your records. If at any time, either now or later, you have a question, you are free to ask it, and you may contact the researcher, Dr. Charles Hillman (217-244-2663, chhillma@illinois.edu), who is responsible for this study. If you have any questions, complaints, or concerns about your *rights as a research participant* in the study, please contact the University of Illinois Institutional Review Board at 217-333-3670 (collect calls are accepted if you identify yourself as a research participant) or via email at irb@illinois.edu.

Before you agree to participate, please check each box below indicating that you:

☐ Understand the procedure.

☐ Give your consent voluntarily.

☐ Know that you can withdraw your consent at any time.

I the undersigned, hereby consent for my child to be a participant in the project described above conducted in the Department of Kinesiology and Community Health at the University of Illinois.

Child Participant's Name: ____________________________
(Please print)

Signature of guardian: ______________________________ Date: ____________________

Signature of experimenter: ___________________________ Date: ____________________

UNIVERSITY OF ILLINOIS
APPROVED CONSENT
VALID UNTIL
SEP 14 2012

APPENDIX C: INFORMED ASSENT FORM

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Department of Kinesiology & Community Health

Louise Freer Hall
906 South Goodwin Avenue
Urbana, IL 61801-3895
217 244-2663 *office*
e-mail: chhillma@illinois.edu
http://www.kines.illinois.edu

"Aerobic Fitness and the Attentional Blink in Preadolescent Children"

Investigator Directing Research: Charles Hillman, Ph.D., University of Illinois at Urbana-Champaign, (217) 244-2663, chhillma@illinois.edu.

Directions: Hand the child a copy of this script so he/she can read along with you. Please read the following script to the child prior to administering the test.

Script:

Hi, my name is _______________ and I am a scientist at the University of Illinois. I am going to give you some information and invite you to be part of a research study. You can choose whether or not you want to participate. We have discussed what you will be doing today with your parent(s)/guardian, and they know that we are also asking you if you would like to participate. If you are going to participate in the research, your parent(s)/guardian also have to agree. But even if your parents have agreed, if you do not wish to take part in the study, you do not have to. As I explain what we are going to ask you to do, there may be some words you don't understand or things that you want me to explain more because you are interested or concerned. Please ask me to stop at anytime and I will take time to explain.

We are interested in finding out how exercise may change the way you think. During the study we will ask you to visit us on two different days. On the first day, today, we will ask you to look at pictures and answer questions. While we are doing this, your parent will be answering questions about your health and daily activities. We will then ask you to perform an exercise test. Before the exercise test, we will show you the treadmill and a breathing mouthpiece that you will be using and let you get comfortable with them. We will also ask you to wear a heart rate monitor, which is a band around your chest that tells us how fast your heart is beating. This band should not bother you in any way, and after a few minutes you won't even remember that you are wearing it. During the exercise test we will ask you to walk or run on the treadmill and every two minutes we will raise the treadmill to make it a bit harder for you to exercise. Your task will be to stay on the treadmill for as long as you can. We want you to do your best, but if at any time you wish to stop, you can. It is your decision. I do need to tell you there is a small risk that you could get hurt while exercising. This means that you might be short of breath for a few minutes after you exercise or that your muscles might be sore the next day. This risk is small and you will have several people surrounding you the entire time you are on the treadmill. This first day will take about one hour. On your next visit, you will look at some letters and numbers on a computer screen and make choices by pushing buttons. While you sit in front of the computer, we will have you wear a special cap (kind of like a swim cap) that allows us to look at the activity in your brain. We will show you the cap and tell you how it works before placing it on your head. However, you should know that some people do not like the cap because it feels uncomfortable to them. If you don't like it or want to take it off, you just need to ask. Sometimes, we can fix what bothers you, but other times people just don't like it. We will ask you how you are doing many times, but you should know that you can tell us how you are doing any time you like. The second day will take about two hours.

Everything you do and say while participating in the study will be kept private and the data you are providing us with will be combined with data from other kids and presented as a group. During the study, the things we will have you do have all been done before by other kids and the risks of participating are the same as you would find in everyday life. If you find any of these procedures uncomfortable, you can decide to stop participating at any time. Even though your parent has given their permission for you to be in the project, your participation is voluntary—this means that you can decide whether or not you want to be in the project. Your participation, however, will provide a better understanding of how the brain responds to exercise.

You will be given a copy of the form that I am reading to you. If at any time you have a question, you are free to ask it, and you and your parents may contact the scientist, Dr. Charles Hillman (217-244-2663, chhillma@illinois.edu), who is responsible for this study. If you wish to speak with someone about your *rights as a research participant* in the study, please contact the University of Illinois Institutional Review Board at 217-333-3670 (collect calls are accepted if you identify yourself as a research participant) or via email at irb@illinois.edu. Do you have any questions?

Before you agree to be in the study, please tell me what I am asking you to be a part of.

Please check each box below indicating that you:

- ☐ Understand the procedure.
- ☐ Are choosing to participate because you want to.
- ☐ Know that you can withdraw your agreement to participate at any time.

Your signature below indicates that you agree to participate in this study:

Participant's signature: ______________________________ Date: ____________________

Researcher who read script: ____________________________

APPENDIX D: EDINBURGH HANDEDNESS INVENTORY

EDINBURGH HANDEDNESS INVENTORY

Please indicate your preferences in the use of hands in the following activities by:

Put "+ +" **in the appropriate column**	If your hand preference is so strong that you would never try to use the other hand unless absolutely forced to.
Put **"+" in the appropriate column**	If you prefer to use one hand over the other.
Put a "+" **in both columns**	If you have no preference.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. Please try to answer all of the questions, and only leave a blank if you have no experience at all of the object or task.

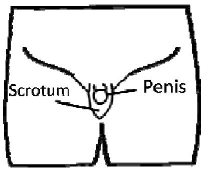
		LEFT	RIGHT
1.	Writing		
2.	Drawing		
3.	Throwing		
4.	Scissors		
5.	Toothbrush		
6.	Knife (without fork)		
7.	Spoon		
8.	Broom (upper hand)		
9.	Striking Match (match)		
10.	Opening Box (lid)		
i.	Which foot do you prefer to kick with?		
ii.	Which eye do you use when using only one?		

APPENDIX E: MODIFIED TANNER STAGING SYSTEM QUESTIONNAIRE

Tanner Staging Questionnaire

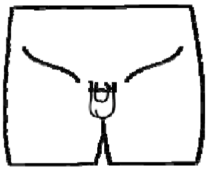
On each side of the line, please circle the number that *best represents* your child's pubertal status.

1.



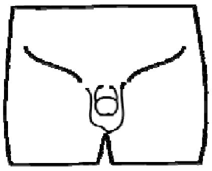
Scrotum and Penis are the same size.

2.



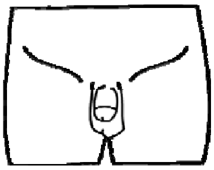
The Scrotum has lowered a bit and the Penis is a little larger.

3.



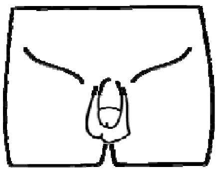
The Penis is Longer and the Scrotum is larger.

4.



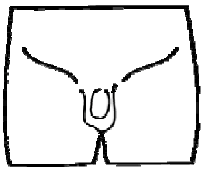
The Penis is longer and wider; the Scrotum is darker and bigger than before.

5.



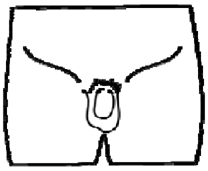
The Penis and Scrotum are the size and shape of an adult.

1.



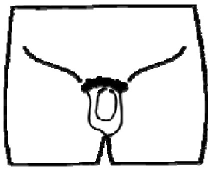
No hairs.

2.



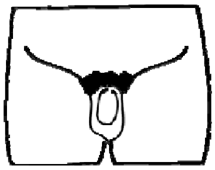
Very little hair.

3.



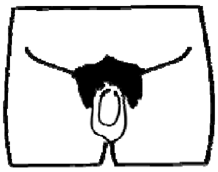
Quite a lot of hair.

4.



The hair has not spread over the thighs.

5.



The hair has spread over the thighs.

Tanner Staging System (Tanner, 1962)

Tanner Staging Questionnaire

On each side of the line, please circle the number that *best represents* your child's pubertal status.

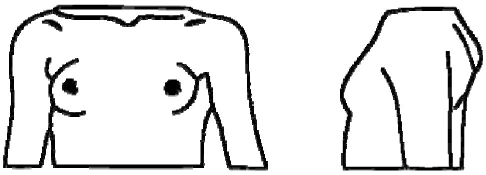
1.

The Breasts are flat.

2.

The breasts form small mounds.

3.

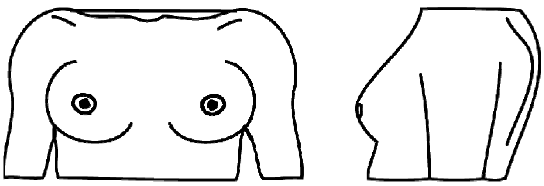


The breasts form larger mounds than in 2.

4.

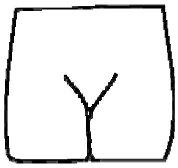
The nipple and the surrounding part (the Areola) make up a mound that sticks up above the breast.

5.



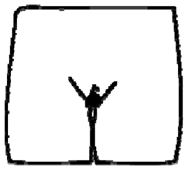
Only the nipple sticks out beyond the breast.

1.



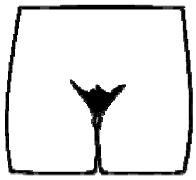
No hairs.

2.



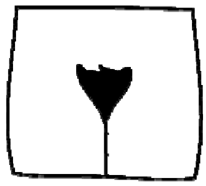
Very little hair.

3.



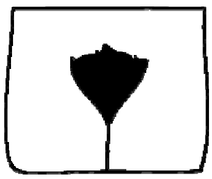
Quite a lot of hair.

4.



The hair has not spread over the thighs.

5.



The hair has spread over the thighs.

Tanner Staging System (Tanner, 1962)

APPENDIX F: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

Common sense is your best guide in answering these few questions. Please read them carefully and check the ☐ Yes or ☐ No opposite the question if it applies to your child.

YES	NO	
☐	☐	1. Has your doctor ever said your child has a heart condition and that they should only do physical activity recommended by a doctor?
☐	☐	2. Does your child feel pain in their chest when they do physical activity?
☐	☐	3. In the past month, has your child had chest pain when they were NOT doing physical activity?
☐	☐	4. Does your child lose their balance because of dizziness or do they ever lose consciousness?
☐	☐	5. Does your child have a bone or joint problem that could be made worse by a change in their physical activity?
☐	☐	6. Is your child's doctor currently prescribing drugs (for example, water pills) for their blood pressure or a heart condition?
☐	☐	7. Do you know of any other reason why your child should not do physical activity?

PAR-Q (Thomas, Reading, & Shephard, 1992)

APPENDIX G: HEALTH HISTORY AND DEMOGRAPHICS QUESTIONNAIRE

Health History & Demographics Questionnaire

Please answer the following questions to the best of your ability.

General Information

1. What was your child's date of birth? _________/_________/_________

2. Was your child born before 38 weeks of pregnancy? ☐ Yes ☐ No

   If yes, how early was your child born? _______________

3. What was your child's birth weight? __________lbs __________oz

4. Did the mother of your child suffer from any medical condition while she was pregnant?

   ☐ Yes ☐ No If yes, what condition?

5. What is your child's current age? _______________

6. What is your child's current (or recently completed) Grade Level? _______________

7. What is your child's sex? ☐ Male ☐ Female

8. Which is your child's dominant hand? ☐ Right ☐ Left ☐No Preference

9. Is your child color blind? ☐ Yes ☐ No

10. Does your child wear contacts or glasses? ☐ Yes ☐ No

    If yes, what was their prescription for?

Demographics

1. Does your child live with their biological parents? ☐ Yes ☐ No

2. Does your child live in a single parent/guardian household? ☐ Yes ☐ No

3. Does your child live with their Mother or a Female guardian? ☐ Yes ☐ No

4. Does your child's Mother/Female guardian work? ☐ Yes ☐ No

5. What is the highest level of education obtained by your child's Mother/Female guardian?
   a) Did not complete high school
   b) High School Graduate
   c) Some College
   d) Bachelor Degree
   e) Advanced Degree

6. Does your child live with their Father or a Male guardian? ☐ Yes ☐ No

7. Does your child's Father/Male guardian work? ☐ Yes ☐ No

8. What is the highest level of education obtained by your child's Father/Male guardian?
   a) Did not complete high school
   b) High School Graduate
   c) Some College
   d) Bachelor Degree
   e) Advanced Degree

9. How many other children (under the age of 18) live with your child? _______________

   How old are they? _______________

   What is their sex? _______________

10. How many biological siblings does your child have? _______________

11. Does your child receive free or reduced-price school lunch? ☐ Yes ☐ No

12. Do you consider yourself to be Hispanic or Latino (*A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race*)? ☐ Yes ☐ No

13. What race / ethnicity do you consider your child?
    a) American Indian or Alaska Native
    b) Asian
    c) Black or African American
    d) Native Hawaiian or other Pacific Islander
    e) White or Caucasian
    f) Mixed or Other

14. What is your approximate household income?

a) <10,000
b) 10,000-20,000
c) 21,000-30,000
d) 31,000-40,000
e) 41,000-50,000
f) 51,000-60,000
g) 61,000-70,000
h) 71,000-80,000
i) 81,000-90,000
j) 91,000-100,000
k) 100,000+

Activities

1. Does your child participate in musical activities? ☐ Yes ☐ No

   If yes:

   Does your child play an instrument? ☐ Yes ☐ No

   If so, what instrument(s)?

   Does your child participate in choir? ☐ Yes ☐ No

   How many hours a week does your child spend participating in musical activities?

2. Does your child participate in religious activities? ☐ Yes ☐ No

   If yes, how many hours a week does your child spend participating in religious activities?

3. Does your child participate in sports activities? ☐ Yes ☐ No

   If yes:

   Does your child participate in formal youth sports? ☐ Yes ☐ No

   In what activities does your child participate?

4. Has your child attended regular afterschool care outside of your home in the last year?

   ☐ Yes ☐ No

Habits

1. How much time does your child spend watching television on an average day during the week?

a) < 1 Hour per Day	f) 5 to 6 Hours per Day
b) 1 to 2 Hours per Day	g) 6 to 7 Hours per Day
c) 2 to 3 Hours per Day	h) 7 to 8 Hours per day
d) 3 to 4 Hours per Day	i) > 8 Hours per Day
e) 4 to 5 Hours per Day	

2. How much time does your child spend watching television on an average day during the weekend?

a) < 1 Hour per Day	f) 5 to 6 Hours per Day
b) 1 to 2 Hours per Day	g) 6 to 7 Hours per Day
c) 2 to 3 Hours per Day	h) 7 to 8 Hours per day
d) 3 to 4 Hours per Day	i) > 8 Hours per Day
e) 4 to 5 Hours per Day	

3. How much time does your child spend on a computer on an average day during the week?

a) < 1 Hour per Day	f) 5 to 6 Hours per Day
b) 1 to 2 Hours per Day	g) 6 to 7 Hours per Day
c) 2 to 3 Hours per Day	h) 7 to 8 Hours per day
d) 3 to 4 Hours per Day	i) > 8 Hours per Day
e) 4 to 5 Hours per Day	

4. How much time does your child spend on a computer on an average day during the weekend?

a) < 1 Hour per Day	f) 5 to 6 Hours per Day
b) 1 to 2 Hours per Day	g) 6 to 7 Hours per Day
c) 2 to 3 Hours per Day	h) 7 to 8 Hours per day
d) 3 to 4 Hours per Day	i) > 8 Hours per Day
e) 4 to 5 Hours per Day	

5. How much time does your child spend playing video games on an average during the week?

a) < 1 Hour per Day	f) 5 to 6 Hours per Day
b) 1 to 2 Hours per Day	g) 6 to 7 Hours per Day
c) 2 to 3 Hours per Day	h) 7 to 8 Hours per day
d) 3 to 4 Hours per Day	i) > 8 Hours per Day
e) 4 to 5 Hours per Day	

6. How much time does your child spend playing video games on an average during the weekend?

a) < 1 Hour per Day	f) 5 to 6 Hours per Day
b) 1 to 2 Hours per Day	g) 6 to 7 Hours per Day
c) 2 to 3 Hours per Day	h) 7 to 8 Hours per day
d) 3 to 4 Hours per Day	i) > 8 Hours per Day
e) 4 to 5 Hours per Day	

7. How much time does your child spend being physically active on an average during the week?

a) < 1 Hour per Day
b) 1 to 2 Hours per Day
c) 2 to 3 Hours per Day
d) 3 to 4 Hours per Day
e) 4 to 5 Hours per Day
f) 5 to 6 Hours per Day
g) 6 to 7 Hours per Day
h) 7 to 8 Hours per day
i) > 8 Hours per Day

8. How much time does your child spend being physically active on an average during the weekend?

a) < 1 Hour per Day
b) 1 to 2 Hours per Day
c) 2 to 3 Hours per Day
d) 3 to 4 Hours per Day
e) 4 to 5 Hours per Day
f) 5 to 6 Hours per Day
g) 6 to 7 Hours per Day
h) 7 to 8 Hours per day
i) > 8 Hours per Day

9. How much sleep does your child regularly get?

a) < 5 Hours per Day
b) 5 to 6 Hours per Day
c) 6 to 7 Hours per Day
d) 7 to 8 Hours per Day
e) 8 to 9 Hours per Day
f) 9 to 10 Hours per Day
g) > 10 Hours per Day

10. How much sleep did your child get last night?

a) < 5 Hours
b) 5 to 6 Hours
c) 6 to 7 Hours
d) 7 to 8 Hours
e) 8 to 9 Hours
f) 9 to 10 Hours
g) > 10 Hours

11. How many caffeinated soft drinks does your child regularly drink in a day?

☐ None ☐ One ☐ Two ☐ Three or more

12. How many cups of tea does your child regularly drink in a day?

☐ None ☐ One ☐ Two ☐ Three or more

13. How often would you rate your child's stress level as HIGH?

☐ Occasionally ☐ Frequently ☐ Constantly

When was the last time your child:

Had a caffeinated substance?

Ate a meal or a snack?

What did s/he have to eat?

Exercised?

What type of exercise?

How long did s/he exercise for?

How intense did s/he work out?

General Health

1. When was the last time your child saw a doctor? ______________________

2. Does your child have any allergies? ☐ Yes ☐ No

3. Has your child ever been diagnosed with dyslexia? ☐ Yes ☐ No

4. Has your child ever been diagnosed with an attentional disorder? ☐ Yes ☐ No

5. Has your child ever been diagnosed with asthma? ☐ Yes ☐ No

6. Is your child epileptic? ☐ Yes ☐ No

7. Is your child diabetic? ☐ Yes ☐ No

   If so please explain:

8. Has your child been diagnosed with any kind of cancer? ☐ Yes ☐ No

   If so please explain:

9. Does your child have hearing loss or wear a hearing aid? ☐ Yes ☐ No

10. Has your child been hospitalized within the last 6 months? ☐ Yes ☐ No

    If so please explain:

11. Has your child ever lost consciousness as a result of hitting their head? ☐ Yes ☐ No

If yes:

When did this occur?

Where did s/he hit his/her head?

How long was s/he unconscious?

12. Has your child ever lost consciousness as a result of any other type of injury or seizure?

☐ Yes ☐ No

If yes:

When did this occur?

How long was s/he unconscious?

Medications/Supplements

Medications: Is your child presently taking or have they taken any of the following medications within the past two months? Please circle your answer.

Asprin, Bufferin, Anacin	Tranquilizers
Blood Pressure pills	Weight reducing pills
Cortisone	Blood thinning pills
Cough Medicine	Dilantin
Digitalis	Allergy Shots
Hormones	Water pills
Insulin or Diabetic pills	Antibiotics
Iron or poor blood medications	Barbiturates
Laxatives	Phenobarbital
Sleeping pills	Thyroid medicine

Other(s):____

1. Does your child take Ginkgo Biloba supplements? ☐ Yes ☐ No

If yes:

When was the last time they took the supplement?

What dose of the supplement did they take?

2. Does your child take Iron supplements? ☐ Yes ☐ No

   If yes:

   When was the last time they took the supplement?

   What dose of the supplement did they take?

3. Does your child take any stimulants or sedatives? ☐ Yes ☐ No

   If yes:

   What do they take?

   When was the last time they took it?

   What dose of it did they take?

Cardiovascular Health

Does your child have any of the following:

1. ☐ Yes ☐ No Pain or discomfort in the chest, neck, jaw, arms, or other areas that may be related to poor circulation.
2. ☐ Yes ☐ No Heartbeats or palpitations that feel more frequent or forceful than usual or feeling that your heart is beating very rapidly.
3. ☐ Yes ☐ No Unusual dizziness or fainting.
4. ☐ Yes ☐ No Shortness of breath while lying flat or a sudden difficulty in breathing that wakes them up while sleeping.
5. ☐ Yes ☐ No Shortness of breath at rest or with mild exertion (such as walking two blocks).
6. ☐ Yes ☐ No Feeling lame or pain in the legs brought on by walking.

7. ☐ Yes ☐ No A known heart murmur.

8. ☐ Yes ☐ No Unusual fatigue with usual activities.

9. ☐ Yes ☐ No Has any **male** in your immediate family had a heart attack or sudden death before the age of 55?

10. ☐ Yes ☐ No Has any **female** in your immediate family had a heart attack or sudden death before the age of 65?

11. ☐ Yes ☐ No Do you have family history of heart disease?

12. ☐ Yes ☐ No Do you have family history of lung disease?

13. ☐ Yes ☐ No Do you have family history of diabetes?

14. ☐ Yes ☐ No Do you have family history of strokes?

15. ☐ Yes ☐ No Has your child been diagnosed with a past or present cardiovascular disease?

16. ☐ Yes ☐ No Does your child have any significant heart rhythm disorder?

17. ☐ Yes ☐ No Has your child been diagnosed with hypertension?

18. ☐ Yes ☐ No Has your child been diagnosed with peripheral vascular disease?

Other

Is there anything else you feel we should know about your child's current/past health?